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Interim Report

Heat and Momentum Transfer to Internal Turbulent Flow of Helium-Argon Mixtures in Circular Tubes

by Paul E. Pickett

CONVECTIVE HEAT TRANSFER FOR SHIP PROPULSION

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The results of an experimental investigation of friction and heat transfer parameters for turbulent flow of helium-argon mixtures in smooth, electrically heated, circular tubes are presented. Experimental results are compared to existing experimental correlations and to analytical results. The variation of turbulent Prandtl number with respect to Reynolds number and molecular Prandtl number is also inspected.

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Interim Report

HEAT AND MOMENTUM TRANSFER TO INTERNAL, TURBULENT FLOW OF HELIUM-ARGON MIXTURES IN CIRCULAR TUBES

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ABSTRACT

The results of an ~~experimental~~ investigation of friction and heat transfer parameters for turbulent flow of helium-argon mixtures in smooth, electrically heated, circular tubes are presented. Experimental results are compared to existing experimental correlations and to analytical results. Results of air and helium from the same experimental apparatus are included for comparison.

In this experiment He-A helium-~~argon~~ mixtures with molecular weights between 15.3 and 29.7 are used, resulting ~~This range resulted~~ in Prandtl numbers between 0.42 and 0.49. Inlet Reynolds numbers range from 31200 to 102000, maximum wall temperatures from 392 to $828^\circ K$, maximum wall-to-bulk temperature ratios to 1.82, maximum wall heat flux values to 511 KW/m^2, and pressures from 469 to 967KPa (4.7 to 9.7 atmospheres).

Existing experimental correlations, developed using gases with Prandtl numbers of approximately 0.7, are compared to the measured friction and heat transfer results. Adiabatic friction factors and friction factors with heat addition are predicted within ± 4 and ± 10 percent, respectively. Nusselt numbers for fully developed, constant property conditions are predicted within ± 5.0 percent. An empirical equation that correlates the helium-argon data within ± 15 percent, and includes entrance and variable

property effects is presented.

Using a recently developed technique that compares numerically calculated and measured constant property Nusselt numbers, turbulent Prandtl numbers in the wall region for helium-argon mixtures are determined. The validity of using these turbulent Prandtl numbers in a variable property numerical analysis is examined. The variation of turbulent Prandtl number with respect to Reynolds number and molecular Prandtl number is also inspected.

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NOMENCLATURE

a,	exponent used to account for temperature variation of viscosity;
a_i,	array of system parameters;
A',	calibration constant for the laminar flow element;
A_{cs},	cross sectional area of tube;
b,	exponent used to account for temperature variation of conductivity;
B',	calibration constant for the laminar flow element;
c,	velocity of sound;
c_p,	specific heat at constant pressure;
D,	inside diameter;
E,	voltage drop;
g,	gravitational constant;
g_c,	dimensional conversion factor;
G,	mass flow rate per unit area;
h,	heat transfer coefficient;
i,	enthalpy per unit mass;
k,	force constant in Lennard-Jones (6-12) potential;
K,	thermal conductivity;
L,	length between pressure taps in laminar flow element;
ℓ,	mixing length;
$\dot{m}$,	mass flow rate;
$\hat{M}$,	molal mass;

ΔP, pressure drop;

P, power;

q, heat transfer rate;

q', heat transfer rate per unit length;

q'', heat flux;

Q, volume flow rate;

r, radius;

R, gas constant for a particular gas;

R', resistance per unit length;

$\mathcal{R}$, universal gas constant;

T, temperature;

u, velocity in axial direction;

x, axial distance from start of heating;

y, radial distance from wall;

Y_i, array of measured values;

Z, a calculated quantity.

Greek symbols

α, thermal diffusivity, $K/c_p\rho$;

ε, force constant in Lennard-Jones potential;

ε_H, eddy diffusivity for heat;

ε_M, eddy diffusivity for momentum;

γ, ratio of specific heats, c_p/c_v;

κ, von Karman constant
0.4;

μ, absolute viscosity;

ν, kinematic viscosity;

ρ, density;

σ, variance or standard deviation;

τ, shear stress.

Non-dimensional parameters

f, friction factor, $2g_c\rho\tau_w/G^2$;

Gr, Grashof number based on wall heat flux, $gD^4q''_w/(\nu^2\mu c_pT)_i$;

M Mach number, j/c

Nu, Nusselt number, hD/K;

Pr, Prandtl number, $c_p\mu/K$;

q^+, heat flux parameter, $q''_w/(Gc_{p,i}T_i)$;

Re, Reynolds number, GD/μ;

y^+, wall distance parameter, $y(g_c\tau_w\rho)^{\frac{1}{2}}/\nu$;

y_ℓ^+ empirical constant in van Driest mixing length model, 26.

Subscripts

b, evaluated at bulk temperature;

cond, heat conduction;

cp, constant property condition;

DB, Dittus-Boelter;

gen, heat generation;

i, inlet; an index;

Max, maximum;

ref, reference;

t, turbulent;

VD, van Driest;

w, wall;

Xe, xenon;

∞, environment conditions.

INTRODUCTION

The closed Brayton cycle using inert gases as working fluids has been considered for use in many current applications. The Navy has investigated its use for undersea and surface ship propulsion. NASA has examined it for future space missions requiring relatively large amounts of electric power (100 - 500 Kw) [1,2,3,4]. Binary mixtures of helium and heavier inert gases, such as argon or xenon, have been considered as possible working fluids in these closed Brayton systems. The increase in density, due to the heavier inert gas, reduces the size of the compressor and turbine. The thermal conductivity of the binary mixture is lower than that of helium, thus causing an increase in the size of the heat exchangers. At an intermediate molecular weight an optimum can be attained.

Fig. 1 illustrates the relative heat transfer of helium-argon and helium-xenon mixtures compared to the pure gases and air. The relative heat transfer coefficients were calculated using the Dittus-Boelter type relation

$$h = 0.021\ Re^{0.8}\ Pr^{0.4}\ (K/D) \qquad (1)$$

and were normalized with respect to the lowest value. The geometry and mass flux were kept constant. This resulted in a relative heat transfer coefficient of the form

$$h/h_{Xe} = (c_p \mu_{Xe}/c_{pXe}\mu)^{0.4}(K/K_{Xe})^{0.6}. \qquad (2)$$

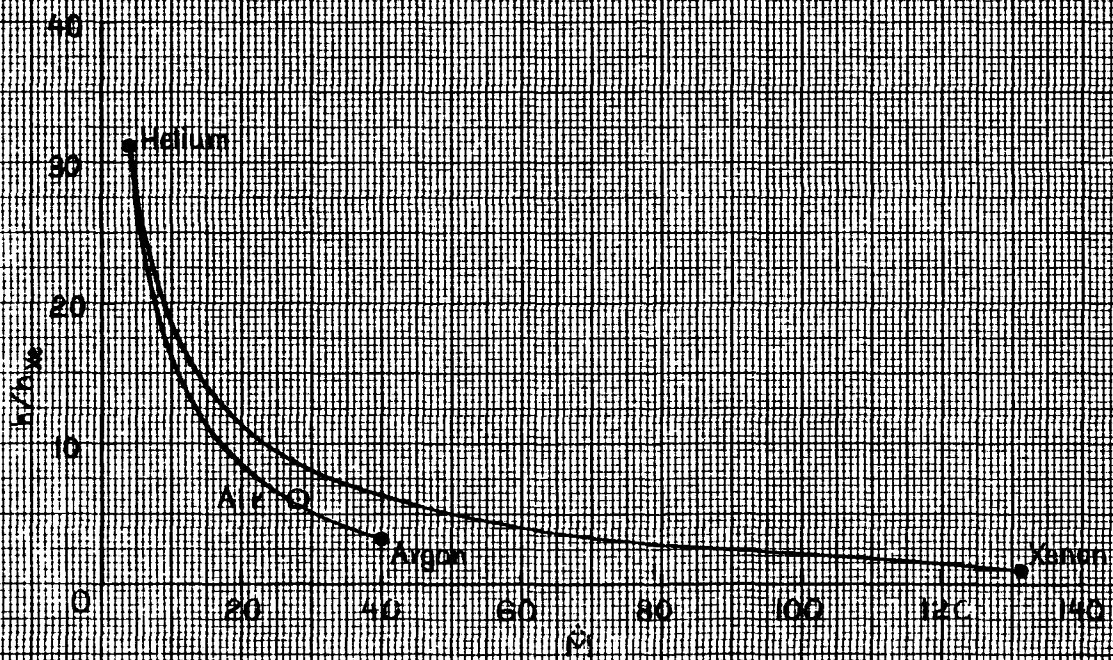


Fig. 1. Relative heat transfer coefficients of mixtures of helium-argon and helium-xenon compared to air and the pure gases, helium, argon, and xenon. Properties were taken at 860K and 101KPa.

All properties were taken at 860K and 101KPa. Vanco [4] performed a similar analysis, but kept the geometry and molal flow rate constant, which gave quite different curves. Examination of Fig. 1 shows why helium-xenon is the prime candidate for a working fluid in the closed Brayton cycle. Helium-argon has been investigated initially due to expense and convenience of experimental apparatus.

The purpose of this research was to determine, for turbulent flow in tubes, the momentum and heat transfer characteristics of helium-argon mixtures. No basic momentum and heat transfer experimental work for fluids with Prandtl numbers between 0.1 and 0.67 presently exists in the literature. Until recently, it was thought that no fluids existed in this Prandtl number range [5,6]. The mixtures of helium and heavier inert gases fill this void, having Prandtl numbers between 0.25 and 0.67. Fig. 2 shows the variation of molecular Prandtl number, Pr, as a function of molecular weight and temperature for helium-argon and helium-xenon [7]. It can be seen that the Prandtl number varies little with temperature.

Experimental correlations, such as equation 1, were developed using air ($Pr \simeq 0.7$) and helium ($Pr = 0.67$). Extension of similar experimental correlations for calculating adiabatic friction factors, average friction factors with heat addition, Nusselt numbers at constant property

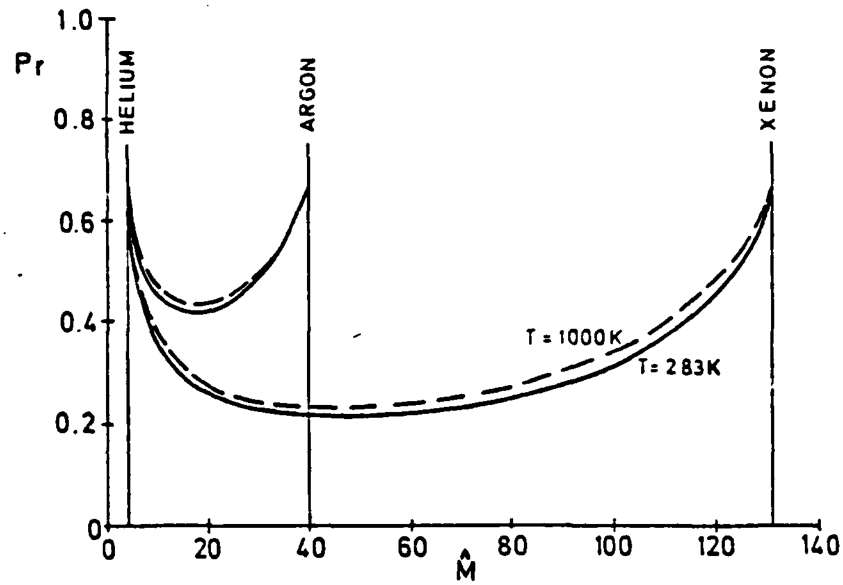


Fig. 2. Variation of Prandtl number with respect to molecular weight for helium-argon and helium-xenon.

conditions, and Nusselt numbers with variable property and thermal entry effects included were examined in this study using helium-argon mixtures. Mixtures at molecular weights of approximately 15 (Pr = 0.42), 27 (Pr = 0.46), and 30 (Pr = 0.49) were used. For comparison, experiments with air and helium were also performed. Experimental studies similar to this one, except using air, helium, or hydrogen include those by Perkins and Worsøe-Schmidt [8], McEligot and Magee [9], Taylor [10], and Dalle Donne and Bowditch [11].

In many analyses that predict turbulent heat transfer results, the value of the turbulent Prandtl number is needed [12]. The turbulent Prandtl number, Pr_t, is defined as the ratio of eddy diffusivity of momentum and eddy diffusivity of heat, $\varepsilon_M/\varepsilon_H$. The eddy diffusivities are defined by the transport relationships,

$$\begin{aligned} \tau/\rho &= (\nu + \varepsilon_M)\frac{\partial u}{\partial y} \\ q''/\rho c_p &= -(\alpha + \varepsilon_H)\frac{\partial T}{\partial y} \end{aligned} \tag{3}$$

and are used to account for the additional momentum and heat transport caused by turbulent mixing.

Much work has been done, both analytical and experimental, to develop methods to predict Pr_t. As of yet, no generally accepted method exists. Reynolds [13] examined more than thirty ways that have been developed to determine Pr_t. For more background information his review can be consulted. Quarmby and Quirk [14] demonstrated the wide

range of Pr_t values that are predicted by different analyses and measured data. For air and other common gases, they showed that different methods predict Pr_t near the wall from 0.5 to infinity.

Due to large uncertainties [15], experimental measurements haven't clarified the discrepancies. The measurements have indicated that Pr_t is a function of Pr, position in the flow, and turbulence intensity [13]. It has been generally observed that Pr_t increases as the wall is approached, and that the relationship between Pr_t and Pr is [12,13]

$$Pr_t \lesseqgtr 1 \text{ for } Pr \gtreqless 1 \text{ unless } Pr \sim 1. \quad (4)$$

A recent technique, developed by McEligot, Pickett, and Taylor [16], determines Pr_t in the wall region by comparing the experimentally measured and numerically calculated axial variation of Nusselt number. The Nusselt numbers are calculated for the constant properties condition, and the measured Nusselt numbers are extrapolated to a constant properties condition. The technique was used in this investigation to determine Pr_t in the wall region for mixtures of helium-argon. By comparing Pr_t for helium-argon mixtures with results for air [16], the variation of Pr_t as a function of Pr was examined. The variation of Pr_t as a function of Reynolds number was also examined.

Relatively high heating rates could possibly occur

in the heater tubes of the closed Brayton cycle. These high heating rates cause significant variation of properties, and the constant properties idealization becomes invalid. To calculate bulk Nusselt numbers of helium-argon mixtures at these conditions, the Pr_t determined for constant properties was used in a numerical analysis in which the properties were allowed to vary. To validate using Pr_t determined for constant property conditions in a variable properties analysis, calculated and measured bulk Nusselt numbers were compared. By examining this comparison, the possibility that the helium and argon had separated, due to the Soret effect [17], was examined.

GAS PROPERTIES

The properties needed for this study were the compressibility, viscosity, thermal conductivity, specific heat, enthalpy, speed of sound, and gas constant. The properties of air have been studied extensively, and tables listing these properties are readily available. The Tables of the Thermal Properties of Gases [18] were used in this investigation. The properties of helium and helium-argon mixtures were calculated theoretically. For all of the gases, the viscosity and thermal conductivity were assumed to be independent of pressure.

The helium and helium-argon mixtures were assumed to be ideal gases, thus making the compressibility equal to a constant value of one. This is a reasonable assumption for the range of pressures (101.3 - 967.3KPa) and temperatures (294 - 828°K) used in this experiment. Since helium and argon are monatomic, and the temperatures used in this study were not too great, the equation [19]

$$c_p = (5/2)\,R \qquad (5)$$

was used to calculate the specific heat. The specific heat was assumed to be constant, and the gas constant was calculated from the relation

$$R = \mathcal{R}/\hat{M}. \qquad (6)$$

Using the ideal gas and constant specific heat assumptions, simple equations for the enthalpy and speed of sound can

be derived [20]

$$i = c_p \ (T - T_{ref}) \qquad (7)$$

$$c = \sqrt{\gamma \ R \ T} = \sqrt{5/3 \ R \ T} \qquad (8)$$

T_{ref} is an arbitrary reference temperature. From the assumptions already mentioned, the ratio of specific heats, γ, becomes a constant value of 5/3.

The viscosity and thermal conductivity of the helium and helium-argon mixtures were calculated using the Lennard-Jones (6-12) potential in the Chapman-Enskog kinetic theory [17]. The predicted properties were compared with experimental measurements.

The force constants, ε/k and σ, suggested by Hirschfelder, Curtiss and Bird [17] were tried originally. The predicted properties were compared with the experimental values only for the range of temperatures used in this study. The predicted helium viscosities were five percent below the experimental measurements of Dawe and Smith [21] and Kalelkar and Kestin [22]. The predicted thermal conductivities of helium agreed within one percent of the measurements by Saxena and Saxena [23], but were five percent below the values calculated from experimental viscosity measurements of Kalelkar and Kestin [22]. The predicted viscosities of helium-argon mixtures at 870°K were three to five percent below the measured values of Kalelkar and Kestin [22]. The predicted thermal conductivities of helium-argon mixtures at 790°K were five to

nine percent below the measured values of the Thermophysical Properties Research Center [24], and the measured values of von Ubisch repeated by Gandhi and Saxena [25].

In an attempt to get better agreement between predicted and measured values, force constants suggested by DiPippo and Kestin [26] were tried. With these force constants, the predicted viscosities of both helium and helium-argon agreed within one percent of the measured values mentioned in the previous paragraph. The predicted thermal conductivities of helium agreed within one percent of the values of Kalelkar and Kestin [22], but were five percent above the measurements of Saxena and Saxena [23]. The predicted thermal conductivities of helium-argon were essentially unchanged. Since the agreement between the predicted and measured viscosities was improved, and the agreement between the predicted and measured thermal conductivities remained approximately the same, the force constants suggested by DiPippo and Kestin [26] were used. The calculated properties of helium and the helium-argon mixtures used in this investigation are listed in Appendix A.

The properties were inserted in tabular form in the numerical programs that reduced the experimental friction and heat transfer measurements. In the numerical program used to predict heat transfer results, the properties were inserted in equation form. The ideal gas law was used, the specific heat was assumed constant, and the variation

of viscosity and thermal conductivity with temperature was accounted for with the following relations.

$$\mu/\mu_{ref} = (T/T_{ref})^a \tag{9}$$

$$K/K_{ref} = (T/T_{ref})^b \tag{10}$$

As discussed by McEligot, Taylor, and Durst [7], the exponent "a" ranges from 0.7 to 0.8, and the exponent "b" ranges from 0.7 to 0.75 for the inert gases and their mixtures. The exponents, "a" and "b", of air for the range of temperatures in this study are 0.67 and 0.81, respectively. Thus, the viscosity and thermal conductivity of air, helium, and helium-argon vary with temperature in approximately the same manner.

For the present study the following values of the exponents were used for the mixtures:

at $\hat{M} = 15.83$, $a = 0.745$ and $b = 0.718$

at $\hat{M} = 27.53$, $a = 0.772$ and $b = 0.741$.

EXPERIMENTAL APPARATUS AND PROCEDURE

The experimental apparatus, arrangement, and procedure was similar to that used by Perkins, Schade, and McEligot [27]. Only differences in the two experiments will be noted here. Instead of a square duct, a circular tube made of Hastelloy-X was used as a test section. The tube had an inside diameter of 0.312 cm. and a wall thickness of 0.056 cm. The test section consisted of a heated section 98 diameters in length preceded by an unheated section 92 diameters in length. The unheated section ensured that the velocity profile was fully developed at the inlet of the heated section. For attachment of the a.c. power cables, stainless steel electrodes were brazed at the upper and lower ends of the heated section. Two pressure taps were used. One was located in the lower electrode and the other 8.0 diameters below the upper electrode. Sixteen premium grade chromel-alumel thermocouples (0.013 cm. diameter) were spot welded to the heated section of the tube using the parallel junction suggested by Moen [28].

In addition to the power supply used by Perkins et al. [27], an a.c. Lincoln welder was used in order to reach the high temperatures at the larger Reynolds numbers used in this experiment. To measure the higher flow rates, the positive displacement meter was replaced by a Meriam

laminar flow element. The latter was calibrated to measure the flow rate within ± 1.5 percent. Heise gages, inclined water manometers, and vertical mercury or water manometers were used to measure static pressure and pressure drop.

A vacuum external environment was not used in this experiment. The test section was completely enclosed with a heat shield that restricted the convective air currents and helped stabilize the heat loss from the tube to the environment.

The experimental procedure was slightly different than that used by Perkins et al. [27]. The "radiating thermocouple conduction error", discussed by Hess [29], was not exactly appropriate since the test section was surrounded by air at atmospheric pressure. Instead a correlation for natural convection from small wires was introduced, in addition to radiation, as detailed in Appendix E. The heat loss from the tube to the environment was determined using the method described by Campbell and Perkins [30].

To reduce the heat transfer data the same computer program that was used by Perkins et al. [27], was employed in this study, but was modified for use with a circular tube. The basics of this computer program are described

in other reports [30,31,32]. Table 1 summarizes the range of variables covered in this investigation. A more detailed discussion of the experiment is contained in Appendix B. A list of the experimental data is contained Appendix D.

TABLE 1

Range of Variables in the Present Experiment

	Air	Helium	Helium-Argon
Experimental runs	25	4	28
Molecular weight	28.97	4.003	15.30 - 29.70
Inlet bulk Reynolds number	32,900 - 100,000	30,200	31,200 - 102,000
Exit bulk Reynolds number	19,900 - 83,000	18,400 - 26,600	17,000 - 68,000
Inlet bulk Prandtl number	0.719	0.667	0.419 - 0.486
Exit bulk Prandtl number	0.682 - 0,708	0.667	0.426 - 0.495
Maximum T_w/T_b	1.90	1.75	1.82
Maximum T_w (^oK)	817	789	828
Maximum q^+	0.0027	0.0027	0.0032
Maximum Gr/Re_i^2	8.90×10^{-5}	4.84×10^{-5}	3.22×10^{-3}
Maximum Mach number	0.26	0.25	0.33
x/D for local bulk Nusselt numbers	2.1 - 82.0	2.1 - 82.0	2.1 - 82.0

EXPERIMENTAL RESULTS

Friction Results

Adiabatic friction factors were measured before each series of heated runs. These were compared to other researcher's results, and were also used as a check of the pressure, mixture molecular weight, and flow rate measurements. The method described by Shapiro [33] was used to calculate the adiabatic friction factors. The measured friction factors were compared to the experimental correlation of Drew, Koo, and McAdams [34],

$$f = 0.0014 + 0.125\ Re^{-0.32}. \qquad (11)$$

This correlation is for turbulent flow in tubes, and was used because of its simplicity and close agreement with the Kármán-Nikuradse relation. Fig. 3 shows the measured friction factor divided by that calculated from equation (11) plotted as a function of Reynolds number. Air and helium data points are included for comparison. All the measured friction factors are within ±4.0 percent of equation (11), and 76 percent are within ±2.0 percent.

Since only two pressure taps were used, local friction factors could not be determined for experiments with heat addition. Average friction factors were determined in the manner of Humble, Lowdermilk, and Desmon [35]. The average friction factors were compared to an experimental correlation suggested by Taylor [36]. This correlation is for

turbulent flow in tubes with heat addition.

$$f = (0.0014 + 0.125\ Re_w^{-0.32})\ (T_w/T_b)^{-0.5} \qquad (12)$$

This relation is similar to equation (11), but the bulk Reynolds number is replaced by the modified wall Reynolds number. The term $(T_w/T_b)^{-0.5}$ is included to account for variation of properties with temperature. Equation (12) was used by Taylor to correlate average friction coefficients measured by several different people. It predicted most of the data within ±10 percent.

Fig. 4 shows the average friction factors with heat addition as measured in this investigation. The friction coefficients are divided by equation (12) and plotted as a function of modified wall Reynolds number. Again, helium and air are included for comparison. All of the data is predicted to within ±10 percent by equation (12) and 84 percent is predicted to within ±4.0 percent.

Heat Transfer Results

To determine the effects of the lower helium-argon Prandtl number on the heat transfer results, the variation of properties with temperature, and the entrance effects were minimized. The entrance effects were minimized by considering primarily the results at which fully developed conditions existed (x/D>20). A method described by Malina and Sparrow [37] was used to approach the constant properties idealization.

For the method described by Malina and Sparrow, a

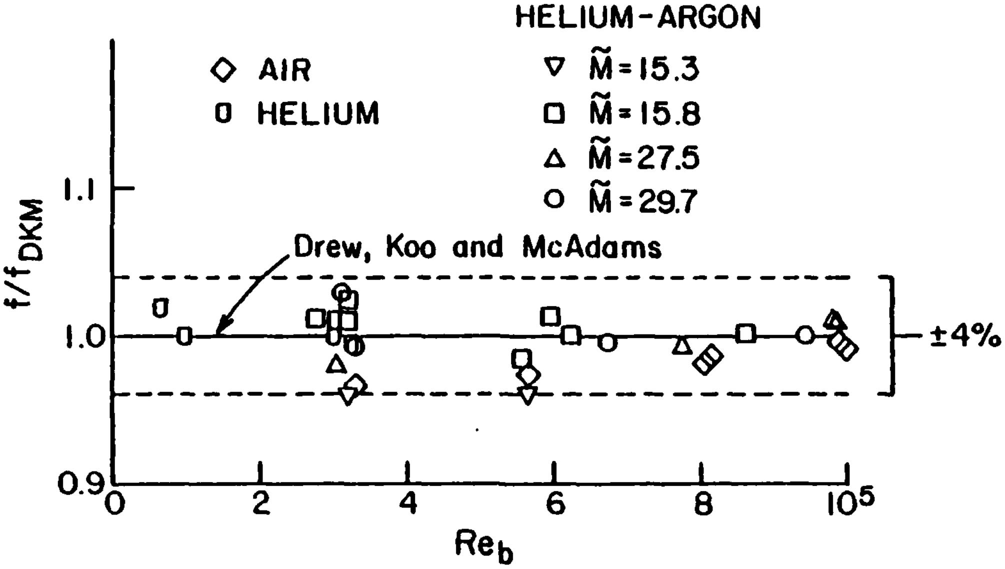


Figure 3. Comparison of Adiabatic Friction Factors to Drew, Koo and McAdams Correlation for Air, Helium and Helium-Argon Mixtures.

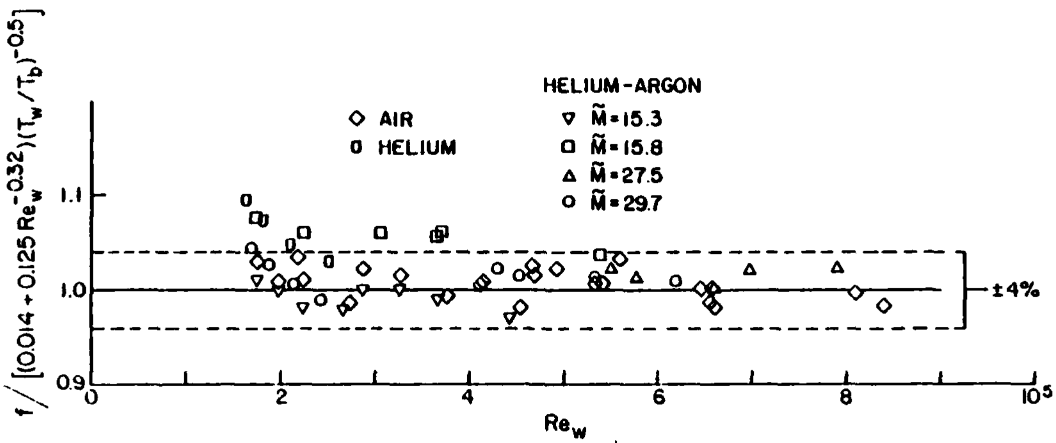


Figure 4 Comparison of Average Friction Factors to Taylor Variable Properties Correlation for Air, Helium and Helium-Argon Mixtures.

fixed inlet Reynolds number is maintained while the wall-to-bulk temperature difference is varied. At a particular axial location, the ratio of experimentally determined bulk Nusselt number to a Dittus-Boelter type correlation is plotted as a function of the difference between wall and bulk temperature. Extrapolation to a difference of zero between the wall and bulk temperature gives a ratio that can be directly used to calculate a constant property Nusselt number, Nu_{cp}. Since the ratio of bulk Nusselt number to a Dittus-Boelter type correlation partially eliminates any effects caused by small deviations of the Reynolds number, these deviations should be kept as small as possible.

The procedure described in the previous paragraph is demonstrated in Fig. 5 for a helium-argon mixture with a molecular weight of 15.30, inlet Reynolds number of 55200, and inlet Prandtl number of 0.419. Extrapolation for four different axial locations is shown. For this investigation the Dittus-Boelter type correlation used was (equation 1 rearranged)

$$Nu_{DB} = 0.021\ Re^{0.8} Pr^{0.4}. \qquad (13)$$

For a sequence of runs at a nominal inlet Reynolds number, all individual runs had inlet Reynolds numbers within 1.8 percent of the nominal value.

The dashed lines in Fig. 5 show how the error in the constant property Nusselt number was estimated. This

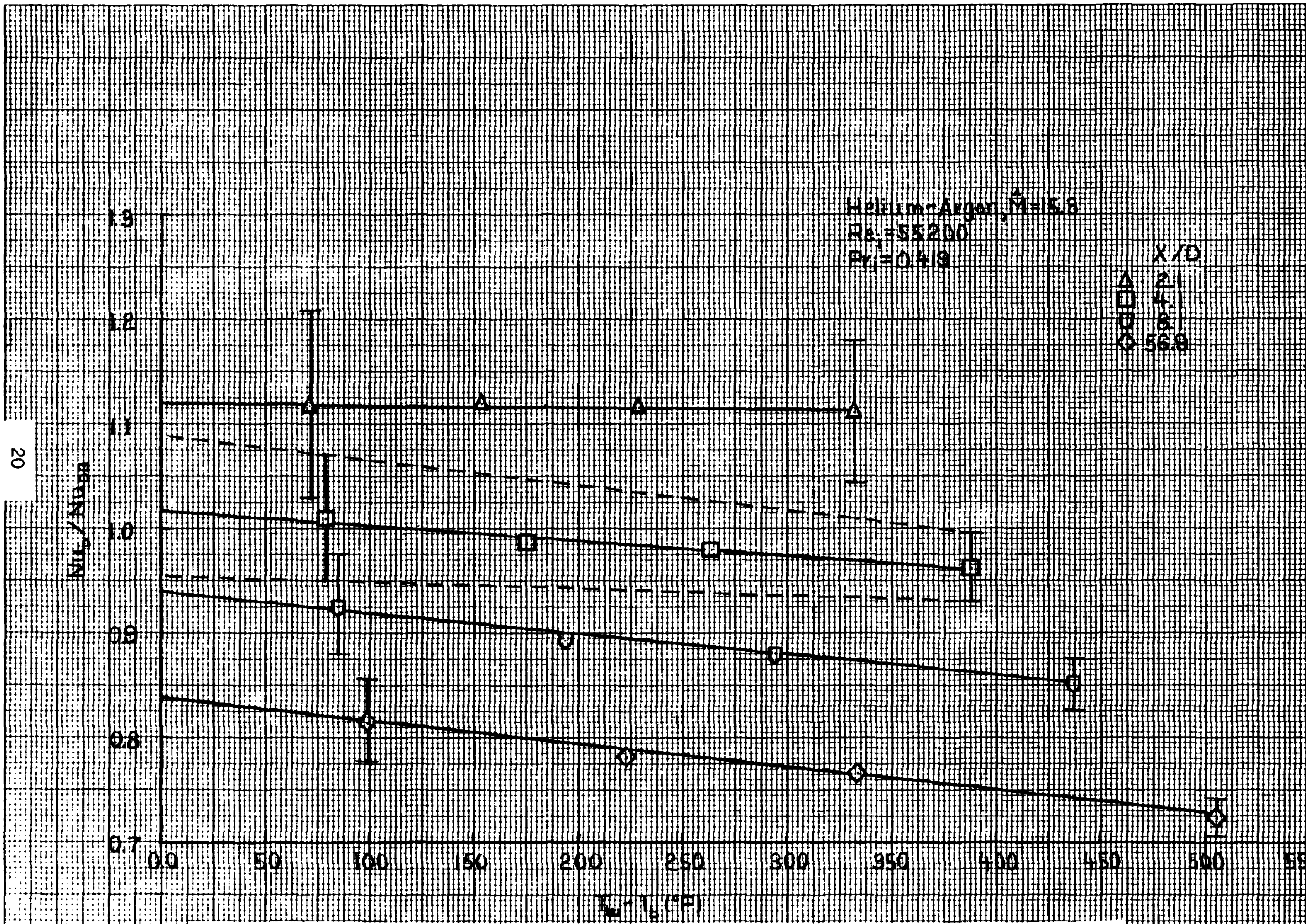


Fig. 5. Technique for determining constant property Nusselt numbers.

technique was used by Reynolds, Swearingen, and McEligot [38]. The error in this investigation varied from ±9 percent at small x/D to ±5.4 percent at large x/D. The dominant uncertainty in the Nusselt number is due to uncertainty in the wall-to-bulk temperature difference. This difference is small in the entrance region, thus causing a large error in the Nusselt number. At large x/D, the flow is fully developed and the wall-to-bulk temperature difference is relatively constant. The error in the Nusselt number becomes a minimum, and then increases with increasing x/D due to greater uncertainty in the bulk temperature. Appendix C describes the method used for calculating error in the measured Nusselt number.

For fully developed conditions (x/D>20), with air or helium as the experimental fluid, the ratio Nu_{cp}/Nu_{DB} varied from 0.94 to 1.00. No dependence on Reynolds number was noticed for the Reynolds number range used in this experiment. For fully developed conditions, with helium-argon mixtures as the experimental fluid, the ratio Nu_{cp}/Nu_{DB} varied from 0.83 to 0.93. For a helium-argon mixture at a molecular weight of 15.30, inlet Reynolds number of 55200, and x/D value of 56.9, Fig. 5 shows the ratio Nu_{cp}/Nu_{DB} to be approximately 0.84. From these results, it was determined that the Dittus-Boelter type equation (equation 13) did not predict correct Nusselt numbers for

the Prandtl number range between 0.42 and 0.50.

A correlation suggested by Kays [39] predicted the constant property Nusselt numbers of the helium-argon mixtures within ±6.0 percent.

$$Nu = 0.022\ Re^{0.8} Pr^{0.6} \tag{14}$$

This equation was recommended for fluids with Prandtl numbers between 0.5 and 1.0, constant properties, a constant heat flux boundary condition, and fully developed turbulent flow. If the coefficient of this equation is changed to 0.021, and the Prandtl number exponent adjusted so that approximately equivalent results are obtained, the resulting equation is

$$Nu = 0.021\ Re^{0.8} Pr^{0.55}. \tag{15}$$

This equation shows that the exponent of the Prandtl number in equation (13) should be changed from 0.4 to 0.55 in order to accurately predict the constant property Nusselt numbers of the helium-argon mixtures. Fig. 6 shows the constant property Nusselt number divided by equation (15) plotted as a function of Prandtl number for the mixtures. Results are plotted for three Prandtl numbers, four Reynolds numbers, and axial positions at which the flow was fully developed. From the figure it can be seen that equation (15) predicts the constant property Nusselt numbers within ±5.0 percent. At a Reynolds number of 32000, a small effect of the Prandtl number varying between 0.419 and 0.486 can be noticed.

A dependence on Reynolds number was observed for the

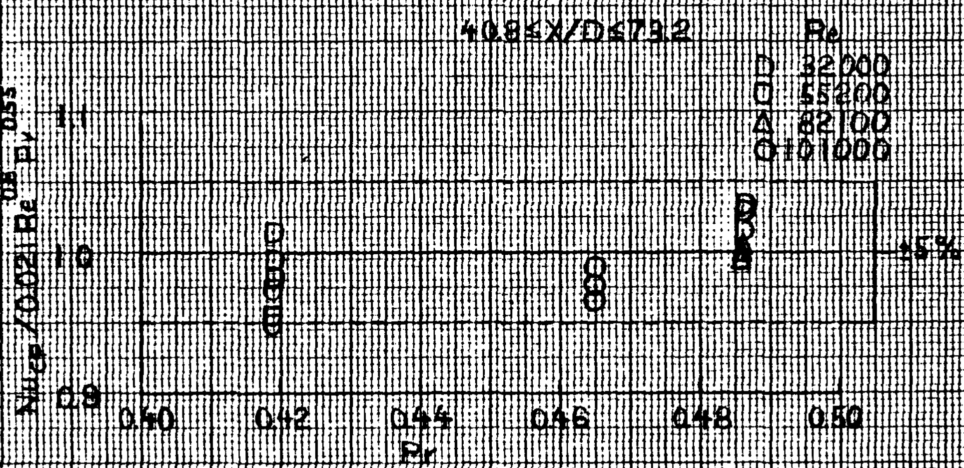


Fig. 6. Comparison of constant property Nusselt numbers to equation 15 for fully developed conditions of helium-argon mixtures.

helium-argon mixtures. Since the effect on the constant property Nusselt number was about equivalent to the error in the constant property Nusselt number, only general trends can be discussed. Two trends were observed (Fig. 6). For a particular Prandtl number the ratio of Nu_{cp} divided by equation (15) decreased as the Reynolds number increased, and this effect became more pronounced as the Prandtl number decreased.

To account for the variation of properties and entrance effects in this investigation, the correction factors suggested by Magee [40] were used.

$$[(T_w/T_b)^{-0.4} + 0.6D/x] \qquad (16)$$

The term $(T_w/T_b)^{-0.4}$ accounts for the variation of properties, and the term 0.6D/x accounts for the entrance effects. If these correction factors are applied to equation (13), the resulting equation is

$$Nu_b = 0.021\ Re_b^{0.8}\ Pr_b^{0.4}[(T_w/T_b)^{-0.4} + 0.6D/x]. \qquad (17)$$

For x/D between 2.1 and 81.6 this equation predicted all of the present measured Nusselt numbers for air and helium within ±15 percent and 97 percent of the Nusselt numbers within ±10 percent.

If the correction factors (16) are applied to equation (15) the resulting relation is

$$Nu_b = 0.021\ Re_b^{0.8}\ Pr_b^{0.55}[(T_w/T_b)^{-0.4} + 0.6D/x]. \qquad (18)$$

This equation predicted the helium-argon Nusselt numbers in the fully developed region within ±13 percent, but

underpredicted the Nusselt numbers in the entrance region by as much as 22 percent. To have the same type of accuracy with the helium-argon data that was obtained with the air and helium data changes to the correlation were necessary.

As previously discussed, the transport properties of helium-argon vary with temperature in approximately the same manner as those of air and helium. For this reason the term $(T_w/T_b)^{-0.4}$ was retained as a reasonably accurate correction factor for the variation of properties. Kays [39] discusses the effect of different Prandtl numbers in the thermal entrance region of circular tubes. He shows that as the Prandtl number decreases, the effect of the entrance region on the Nusselt number is more pronounced. Because of this, the coefficient in the term 0.6D/x of equation (18) was changed. Since helium-argon has a lower Prandtl number than air, one would expect the coefficient to have a larger value than 0.6. Different values for the coefficient of the entrance effects term were used in equation (18), and compared to the experimentally determined bulk Nusselt numbers of helium-argon. From this comparison it was determined that a value of 0.85 worked best for the coefficient of the entrance effects term. The complete correlation, accounting for entrance effects and variation of properties is

$$Nu_b = 0.021\, Re_b^{0.8}\, Pr_b^{0.55} \left[(T_w/T_b)^{-0.4} + 0.85D/x\right]. \quad (19)$$

For x/D between 2.1 and 81.6 this equation predicted all

of the measured bulk Nusselt numbers for helium-argon within ±15 percent and 92 percent within ±10 percent.

Measured bulk Nusselt numbers divided by equation (19) are plotted on Fig. 7 as a function of x/D. For clarity, only results from four helium-argon experimental runs were plotted. The data plotted are from experimental runs that include the complete range of experimental variables for the helium-argon mixtures. The greatest difference between the experimental data and equation (19) occurred at high heating rates in the x/D range between 4.0 and 16.0. In this range equation (19) underpredicted the measured Nusselt numbers by 5 to 15 percent.

Few correlations for gases with Prandtl numbers between 0.1 and 0.67 presently exist in the literature. Sleicher and Rouse [41] suggest a correlation for Prandtl numbers between 0.1 and 10^5, and Reynolds numbers between 10^4 and 10^6. The correlation is for fully developed conditions, and accounts for property variation.

$$\begin{aligned} Nu_b &= 5 + 0.015\, Re_f^{\,m}\, Pr_w^{\,n} \\ m &= 0.88 - 0.24/(4 + Pr_w) \qquad (20) \\ n &= 1/3 + 0.5 \exp(-0.6\, Pr_w) \end{aligned}$$

For the helium-argon mixtures, this equation predicted Nusselt numbers that were 15 to 40 percent lower than the Nusselt numbers measured in the fully developed region of this investigation. Equation (19) correlated the data more accurately.

Molecular Weight	Inlet Re_b	Outlet Re_b	Pr_b	q^+_{Max}	$(T_w/T_b)_{Max}$
D 15.30	54800	36200	0.419	0.0019	1.54
□ 15.83	80600	60900	0.419	0.0012	1.39
Δ 27.53	101000	87500	0.465	0.0005	1.19
O 29.70	31200	17000	0.486	0.0032	1.78

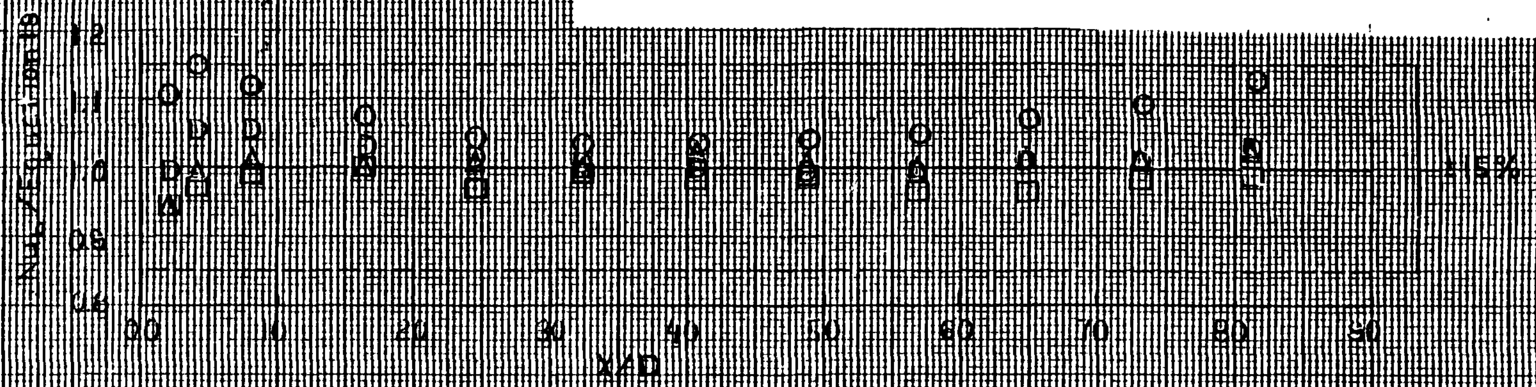


Fig. 7. Comparison of local bulk Nusselt numbers to equation 19 for helium-argon mixtures.

NUMERICAL ANALYSIS

Procedure for Determining the Turbulent Prandtl Number

To determine Pr_t for helium-argon mixtures, the numerical method of Bankston and McEligot [42] was used in conjunction with the technique developed by McEligot, Pickett, and Taylor [16]. The numerical method uses finite control volume approximations. It was developed to solve the coupled, partial differential, axisymmetric, boundary layer equations; but can also be used for constant property conditions which uncouples the boundary layer equations. The boundary conditions are the no-slip and impermeable-wall conditions, the inlet conditions, and the wall heat flux.

The technique of McEligot et al. [16] uses the axial variation of the Nusselt number to determine Pr_t in the wall region. By examination of the simplified energy equation,

$$u \frac{\partial T}{\partial x} = 1/r \frac{\partial}{\partial r}[r(\alpha + \varepsilon_M/Pr_t) \frac{\partial T}{\partial r}] \qquad (21)$$

they showed that the functional dependence of the Nusselt number is

$$Nu = Nu \{x, u(r), \varepsilon_M(r), Pr_t\}. \qquad (22)$$

The energy equation was simplified from the general form by using the following assumptions: the axisymmetric boundary layer approximations, hydrodynamic fully developed flow, steady flow at low velocities, and constant fluid

properties. By using one of the semi-empirical relationships for $\varepsilon_M(r)$ to determine the velocity profile, u(r), they obtained the result Nu = Nu $\{x,Pr_t\}$. They inverted this relationship to obtain $Pr_t = Pr_t \{Nu(x)\}$. If Pr_t is considered one-dimensional, comparison of experimental measurements of Nu(x) with calculated values of Nu(x) can be used to determine $Pr_t(r)$. McEligot et al. [16] pointed out that direct inversion would be difficult, and iterative use of the numerical procedure described in the previous paragraph was used. The radial variation of the turbulent Prandtl number was assumed to be

$$P_r = Pr_{t,w} + \frac{d(Pr_t)}{d(y/r_w)} (y/r_w). \tag{23}$$

The results of McEligot et al. [16] showed that a change of Pr_t in the wall region from 1 to ½ caused changes of 30 to 45 percent in Nu(x), whereas a change of Pr_t in the core only caused small changes. For air at a Reynolds number of 44500 and a Prandtl number of 0.72 they determined that

$$Pr_{t,w} = 0.9 \pm 0.1 \text{ and } \frac{d(Pr_t)}{d(y/r_w)} = 0. \tag{24}$$

The typical errors of the experimentally measured Nusselt numbers did not allow calculation of $\frac{d(Pr_t)}{d(y/r_w)}$.

To determine $\varepsilon_M(r)$ in this investigation, the van Driest mixing length model [43] was used in conjunction with the

Reichardt middle law [54].

$$\ell_{VD} = \kappa y[1 - \exp(-y^+/y_\ell^+)]$$

$$\varepsilon_{VD} = \ell_{VD}^2 \frac{\partial u}{\partial y} \text{ and } \varepsilon_M = \varepsilon_{VD} \cdot (2-\frac{y}{r_w}) \cdot [1+2(\frac{r}{r_w})^2]/6 \qquad (25)$$

The values of κ and y_ℓ^+ were 0.4 and 26, respectively. With these constants, the predicted friction factors agreed within one percent of equation (11) for the range of Reynolds numbers used in this study. In this study, as in the study by McEligot et al. [16], the errors in the experimentally measured Nusselt numbers did not allow calculation of $\frac{d(Pr_t)}{d(y/r_w)}$. The inlet Reynolds number, inlet Prandtl number, constant properties condition, wall heat flux variation, and different values of Pr_t were used as input to the numerical procedure. For the first three diameters, the experimental axial wall heat flux variation resembled an exponential approach to a constant value as x increased. For the remaining length, the wall heat flux was constant within two percent. The same axial variation of wall heat flux was used for all of the constant property numerical calculations.

From the numerical analysis the axial variation of Nu_{cp} was calculated. By comparing graphs of the experimentally measured Nu_{cp} and the calculated Nu_{cp} (examples in Fig. 8), $Pr_{t,w}$ for helium-argon mixtures was determined. The variation of $Pr_{t,w}$ with respect to Reynolds number was examined by comparing Nu_{cp} at different Reynolds numbers,

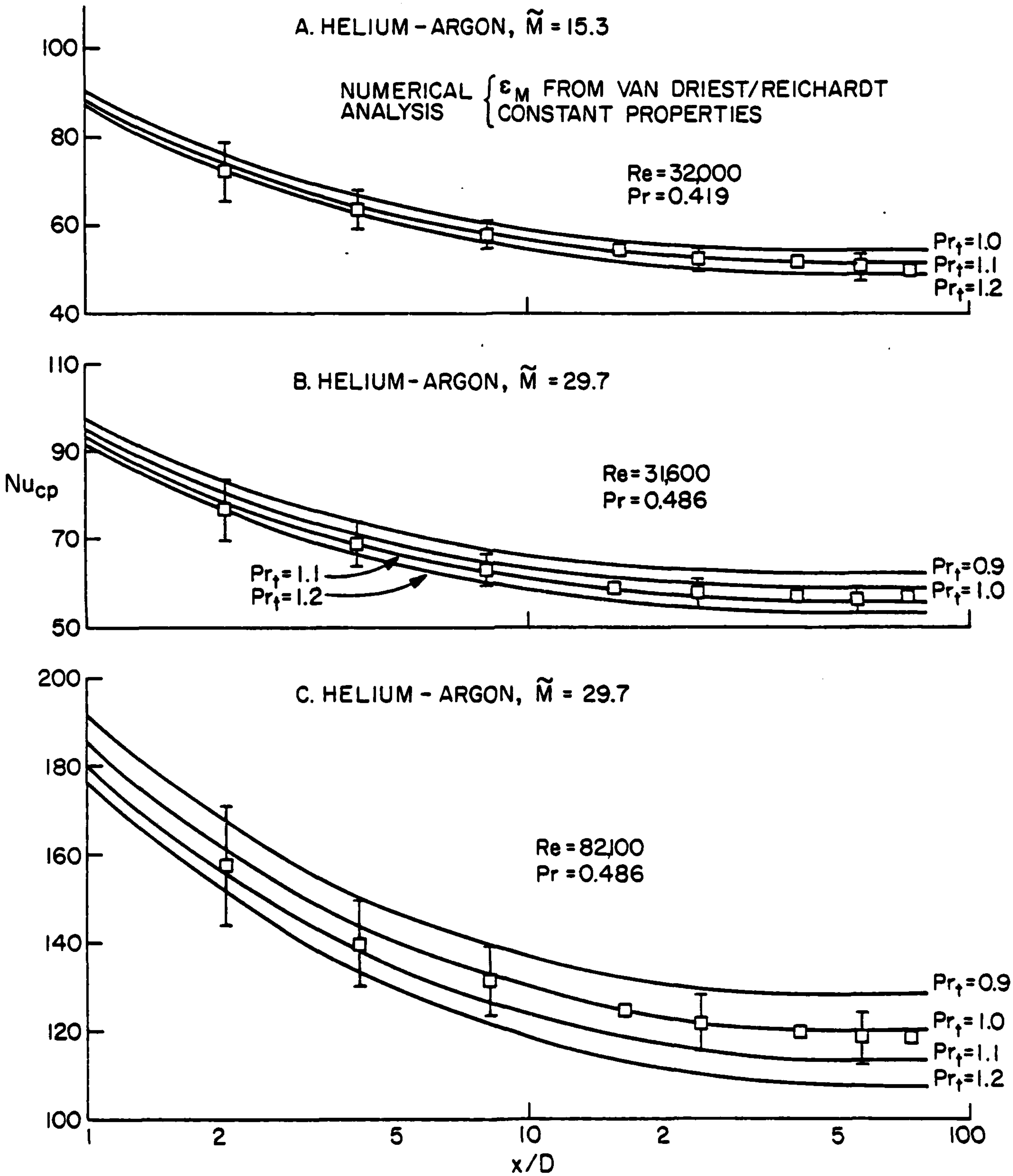


Figure 8. Examples of the Comparisons Between Measured $Nu_{cp}(x)$ and Predicted $Nu(x)$ as Used to Deduce Pr_{tw} for Constant Properties.

but the same Prandtl number. The variation of $Pr_{t,w}$ with respect to Prandtl number was examined by comparing Nu_{cp} at different Prandtl numbers, but the same Reynolds number.

Procedure for Studying High Heating Rates

As mentioned in the Introduction, relatively high heating rates could possibly occur in the heater tubes of the closed Brayton cycle. To calculate Nu_b for helium-argon mixtures at these high heating rates, the numerical method of Bankston and McEligot [42], discussed in the previous section, was used. Properties were allowed to vary, and the relations (9,10) discussed in the Gas Properties section were used. The simple van Driest/Reichardt model eqn. (25), and $Pr_{t,w}$ determined for helium-argon at constant property conditions were incorporated. No radial variation of Pr_t was included, thus, $Pr_t = Pr_{t,w}$. The axial variation of wall heat flux was similar to the one used for the constant property calculations, but was modified slightly for each experimental run to agree with the wall heat flux variation determined from the experimental measurements.

The axial variation of measured Nu_b from two helium-argon experimental runs was compared to the calculated axial variation of Nu_b. From a series of runs with approximately equivalent inlet Reynolds and Prandtl numbers, the runs with the highest and lowest heating rate were

chosen. Since the Pr_t used was for constant properties, one would expect agreement of measured and calculated Nu_b at the low heating rate. If the measured and calculated Nu_b at the high heating rate agreed, this would validate the use of Pr_t determined from constant property conditions for conditions in which properties varied significantly. If the results at the high heating rate did not agree, this might indicate that either, Pr_t determined for constant properties couldnot be used for variable property conditions, or that some other phenomenon, such as the Soret effect, was acting.

<u>Turbulent Prandtl Number Results and Discussion</u>

Fig. 8 illustrates examples of the comparisons between measured Nu_{cp} and calculated Nu_{cp} used to determine $Pr_{t,w}$. Examples for three Reynolds numbers and two Prandtl numbers are shown. Curves of the calculated Nu_{cp} are included at four different Pr_t (0.9,1.0,1.1,1.2). Brackets indicating the experimental error of the measured Nu_{cp} are also included. Because of the large error in the immediate thermal entry, only results for x/D greater than eight were used to determine $Pr_{t,w}$.

Fig. 8a shows the measured and calculated Nu_{cp} for a helium-argon mixture with a molecular weight of 15.30, Prandtl number of 0.419, and Reynolds number of 32000. By examining results of similar graphs, $Pr_{t,w}$ was determined to be 1.1 ± 0.1 for helium-argon mixtures with molecular

weights of approximately 15, Prandtl numbers of 0.42, and Reynolds numbers between 32000 and 55200. The measured and calculated Nu_{cp} are shown in Fig. 8b and 8c for a helium-argon mixture at a molecular weight of 29.70, Prandtl number of 0.486, and Reynolds numbers of 31600 and 82100. From results of similar graphs, $Pr_{t,w}$ was determined to be 1.0 ± 0.1 for helium-argon mixtures with molecular weights between 27 and 30, Prandtl numbers between 0.46 and 0.49, and Reynolds numbers between 31600 and 102000.

The effect of Reynolds number on $Pr_{t,w}$ can be examined qualitatively using the results in Fig. 8b and 8c. These results are for the same Prandtl number (Pr = 0.486), but Reynolds numbers of 31600 and 82100. For x/D greater than eight, and at the low Reynolds number, the measured Nu_{cp} are slightly below the calculated Nu_{cp} for a $Pr_{t,w}$ of 1.0. At the high Reynolds number and same axial length, the measured Nu_{cp} are slightly above the calculated Nu_{cp} for a $Pr_{t,w}$ of 1.0. For the stated conditions, it appears that $Pr_{t,w}$ has a weak dependence on Reynolds number, and decreases slightly as the Reynolds number increases.

The effect of molecular Prandtl number on $Pr_{t,w}$ can be examined using the results from Fig. 8a and 8c summarized in Table 2. The results (24) of McEligot, Pickett and Taylor [16] for air may also be used since the mixture results appear to show that $Pr_{t,w}$ varies only slightly with Reynolds number.

Table 2. Variation of $Pr_{t,w}$ with respect to Prandtl number.

Gas	Molecular Weight	Prandtl Number	$Pr_{t,w}$	Reynolds Number
Helium-argon	15.30	0.419	1.1 ± 0.1	32000
Helium-argon	29.70	0.486	1.0 ± 0.1	31600
Air	28.97	0.72	0.9 ± 0.1	44500

For the range of Prandtl numbers in Table 2, $Pr_{t,w}$ has a relatively strong dependence on Prandtl number and decreases as Prandtl number increases. This dependence agrees with that (equation 4) noted by Reynolds [13].

High Heating Rate Results and Discussion

Fig. 9 shows the results of the measured and calculated axial variation of Nu_b for the two experimental runs that were investigated. The two runs were for a helium-argon mixture at a molecular weight of 29.70, inlet Prandtl number of 0.486, inlet Reynolds numbers of 32000 and 31200, and maximum heating rates of $q^+ = 0.0006$ and $q^+ = 0.0032$. Since at a Pr_t value of 1.0, the measured Nu_{cp} in Fig. 8b were slightly below the calculated Nu_{cp}, a Pr_t value of 1.02 was used. The constants, "a" and "b" in equations (9) and (10) were 0.772 and 0.741, respectively. For both heating rates, the calculated axial variation of Nu_b in Fig. 9 agreed with the measured axial variation of Nu_b, within the accuracy of the measured values. From this example, it appears that $Pr_{t,w}$ determined from constant property results can be used to calculate Nu_b for variable property conditions with heating rates up to, $q^+ = 0.0032$.

At high heating rates a large temperature gradient exists from the wall to the centerline of the tube. At

sufficiently high heating rates, the possibility of separation of the helium and argon due to the Soret effect arises. If separation did occur, Nu_b at a particular axial location would be expected to change since pure helium or argon have higher Prandtl numbers than helium-argon mixtures. For the high heating experimental run in Fig. 9, the largest wall-to-bulk temperature ratios occur in the axial range, $8.1<x/D<16.4$. In this axial range, the measured Nu_b do fall slightly above the calculated Nu_b, but this can not necessarily be attributed to the Soret effect, since the calculated Nu_b are within the experimental accuracies of the measured Nu_b.

The effect of high heating on the axial variation of Nu_b can be examined by comparing the low and high heating rate results in Fig. 9. Since the thermal conductivity and viscosity of helium-argon increase as the temperature increases (equations 9,10), this causes Nu_b for high heat flux conditions to be lower than Nu_b for low heat flux conditions. In the immediate thermal entrance region ($x/D<5$), the small rise in bulk gas temperature has not caused significant bulk property variation, and the Nu_b for the two heating rates are approximately the same. In the fully developed region, the large rise in bulk gas temperature has caused large property variations, and Nu_b are quite different. At $x/D = 57$, Nu_b for $q^+_{Max} = 0.0032$ is 29 percent lower than Nu_b for $q^+_{Max} = 0.0006$.

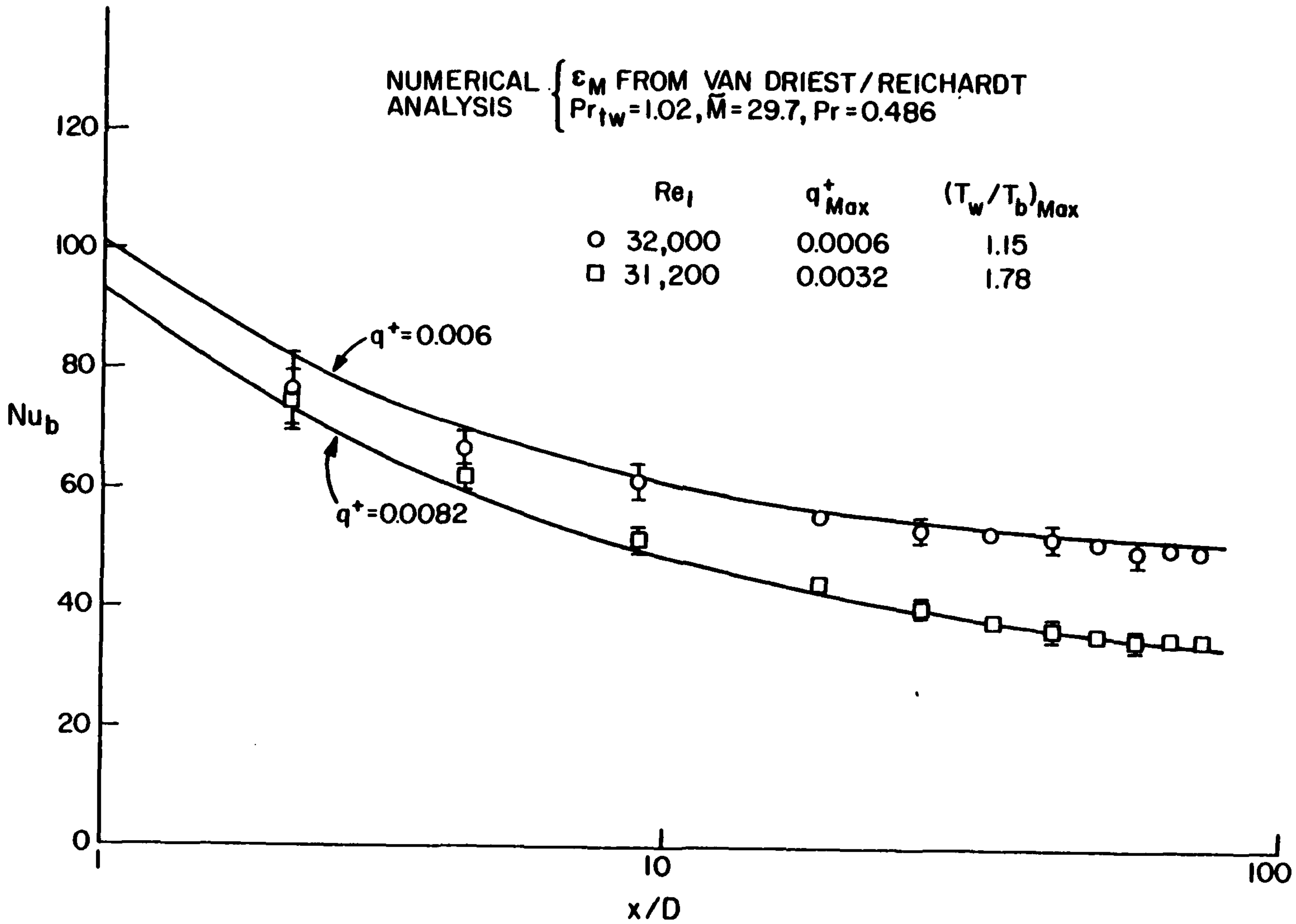


Figure 9. Comparison of Data to Numerical Predictions Accounting for Transport Property Variation.

CONCLUSIONS

The object of this investigation was to study the momentum and heat transfer characteristics for turbulent flow of helium-argon mixtures in tubes. Experimental results were compared to existing experimental correlations, and to results from a numerical analysis. From this investigation the following conclusions have been made:

1. Existing experimental correlations, such as the Drew, Koo, and McAdams relation [34],

$$f = 0.0014 + 0.125\ Re^{-0.32}$$

predict the helium-argon adiabatic friction factors within ±4.0 percent for turbulent flow in tubes with Reynolds numbers between 31200 and 102000.

2. A correlation suggested by Taylor [36],

$$f = (0.0014 + 0.125\ Re_w^{-0.32})\ (T_w/T_b)^{-0.5}$$

predicts average friction factors within ±10 percent for heated turbulent flow of helium-argon mixtures in tubes with inlet Reynolds numbers between 31200 and 102000.

3. Dittus-Boelter type correlations developed from air and helium experimental data

$$Nu = 0.021\ Re^{0.8}\ Pr^{0.4}$$

overpredict helium-argon Nusselt numbers for constant property, fully developed conditions by as much as 17 percent. An equation of similar form,

$$Nu = 0.021\ Re^{0.8}\ Pr^{0.55}$$

but with the exponent of the Prandtl number changed to 0.55 predicts constant property Nusselt numbers of helium-argon mixtures within ±5.0 percent. The range of Prandtl numbers was between 0.419 and 0.486, and the range of Reynolds numbers was between 31200 and 102000.

4. For the same range of Reynolds numbers and Prandtl numbers, the entrance and properties variation effects can be accounted for by using the equation

$$Nu_b = 0.021\ Re_b^{0.8}\ Pr_b^{0.55}\ [(T_w/T_b)^{-0.4} + 0.85\ D/x].$$

This equation predicted the bulk Nusselt numbers of helium-argon mixtures within ±15 percent for x/D between 2.1 and 81.6 and a maximum wall-to-bulk temperature ratio of 1.82.

5. For helium-argon mixtures with molecular weights between 14 and 20, Prandtl numbers of 0.42, Reynolds numbers between 32000 and 55000, and constant property conditions the turbulent Prandtl number in the wall region, $Pr_{t,w}$ was determined to be 1.1 ± 0.1.

6. For helium-argon mixtures with molecular weights between 27 and 30, Prandtl numbers between 0.46 and 0.49, Reynolds numbers between 32000 and 102000, and constant property conditions $Pr_{t,w}$ was determined to be 1.0 ± 0.1.

7. For Reynolds numbers between 30000 and 100000, $Pr_{t,w}$ is a weak function of Reynolds number. For the Prandtl number range between 0.42 and 0.72, $Pr_{t,w}$ is

a strong function of Prandtl number, and decreases as Prandtl number increases.

8. At maximum wall heating rates of $q^+ = 0.0032$ ($(T_w/T_b)_{Max} = 1.78$), $Pr_{t,w}$ determined from constant property conditions can be used in a variable properties numerical analysis to calculate $Nu_b(x)$. For the particular experimental run studied ($Re_i = 31200$, $Pr_i = 0.486$, $Pr_{t,w} = Pr_t = 1.02$), calculated $Nu_b(x)$ agreed with measured $Nu_b(x)$, within the accuracy of the measured values. No separation of the helium-argon mixture was apparent.

APPENDICES

APPENDIX A.
Gas Properties

Helium

Molecular Weight = 4.0026

Specific Heat at Constant Pressure = 1.24036 BTU/LB-R

Temperature (F)	Viscosity (LB/FT-HR)	Conductivity (BTU/HR-FT-F)	Sound Velocity (FT/SEC)
40.00000	4.5339250E-02	8.4353958E-02	3.2161071E+03
70.00000	4.7348801E-02	8.8092741E-02	3.3112430E+03
100.00000	4.9301672E-02	9.1726070E-02	3.4037209E+03
130.00000	5.1202696E-02	9.5262937E-02	3.4937518E+03
160.00000	5.3056299E-02	9.8711577E-02	3.5815203E+03
190.00000	5.4866529E-02	1.0207952E-01	3.6671887E+03
220.00000	5.6637084E-02	1.0537365E-01	3.7509011E+03
250.00000	5.8371342E-02	1.0860025E-01	3.8327355E+03
280.00000	6.0072394E-02	1.1176507E-01	3.9129567E+03
310.00000	6.1743066E-02	1.1487336E-01	3.9915180E+03
340.00000	6.3612572E-02	1.1835159E-01	4.0685526E+03
370.00000	6.5192576E-02	1.2129120E-01	4.1441751E+03
400.00000	6.6752529E-02	1.2419350E-01	4.2184325E+03
430.00000	6.8293346E-02	1.2706020E-01	4.2914052E+03
460.00000	6.9215869E-02	1.2989286E-01	4.3631576E+03
490.00000	7.1320879E-02	1.3269294E-01	4.4337490E+03
520.00000	7.2809100E-02	1.3546179E-01	4.5032339E+03
550.00000	7.4281207E-02	1.3820065E-01	4.5716629E+03
580.00000	7.5737825E-02	1.4091070E-01	4.6390826E+03
610.00000	7.7179543E-02	1.4359302E-01	4.7055364E+03
640.00000	7.8606908E-02	1.4624864E-01	4.7710647E+03
670.00000	8.0020435E-02	1.4887852E-01	4.8357051E+03
700.00000	8.1420607E-02	1.5148355E-01	4.8994928E+03
730.00000	8.2807878E-02	1.5406458E-01	4.9624606E+03
760.00000	8.4182678E-02	1.5662240E-01	5.0246394E+03
790.00000	8.5545409E-02	1.5915777E-01	5.0860581E+03
820.00000	8.6896453E-02	1.6167140E-01	5.1467439E+03
850.00000	8.8236173E-02	1.6416395E-01	5.2067224E+03
880.00000	8.9564910E-02	1.6663608E-01	5.2660179E+03
910.00000	9.0882989E-02	1.6908837E-01	5.3246530E+03
940.00000	9.2190718E-02	1.7152141E-01	5.3826495E+03
970.00000	9.3488391E-02	1.7393574E-01	5.4400277E+03
1000.00000	9.4776287E-02	1.7633188E-01	5.4968070E+03
1030.00000	9.6054671E-02	1.7871032E-01	5.5530057E+03
1060.00000	9.7323797E-02	1.8107153E-01	5.6086414E+03
1090.00000	9.8583908E-02	1.8341598E-01	5.6637306E+03
1120.00000	9.9835234E-02	1.8574408E-01	5.7182390E+03
1150.00000	1.0107800E-01	1.8805625E-01	5.7723319E+03
1180.00000	1.0231241E-01	1.9035288E-01	5.8258734E+03
1210.00000	1.0353867E-01	1.9263435E-01	5.8789273E+03
1240.00000	1.0475693E-01	1.9490102E-01	5.9315068E+03
1270.00000	1.0596752E-01	1.9715323E-01	5.9836242E+03
1300.00000	1.0717047E-01	1.9939133E-01	6.0352915E+03

Helium cont.

Temperature (F)	Enthalpy (BTU/LB)
40.00000	6.1979399E+02
70.00000	6.5700470E+02
100.00000	6.9421541E+02
130.00000	7.3142612E+02
160.00000	7.6863683E+02
190.00000	8.0584754E+02
220.00000	8.4305825E+02
250.00000	8.8026896E+02
280.00000	9.1747967E+02
310.00000	9.5469038E+02
340.00000	9.9190109E+02
370.00000	1.0291118E+03
400.00000	1.0663225E+03
430.00000	1.1035332E+03
460.00000	1.1407439E+03
490.00000	1.1779546E+03
520.00000	1.2151654E+03
550.00000	1.2523761E+03
580.00000	1.2895868E+03
610.00000	1.3267975E+03
640.00000	1.3640082E+03
670.00000	1.4012189E+03
700.00000	1.4384296E+03
730.00000	1.4756403E+03
760.00000	1.5128510E+03
790.00000	1.5500617E+03
820.00000	1.5872725E+03
850.00000	1.6244832E+03
880.00000	1.6616939E+03
910.00000	1.6989046E+03
940.00000	1.7361153E+03
970.00000	1.7733260E+03
1000.00000	1.8105367E+03
1030.00000	1.8477474E+03
1060.00000	1.8849581E+03
1090.00000	1.9221689E+03
1120.00000	1.9593796E+03
1150.00000	1.9965903E+03
1180.00000	2.0338010E+03
1210.00000	2.0710117E+03
1240.00000	2.1082224E+03
1270.00000	2.1454331E+03
1300.00000	2.1826438E+03

Helium-Argon

Molecular Weight = 15.30

Specific Heat at Constant Pressure = 0.32449 BTU/LB-R

Temperature (F)	Viscosity (LB/FT-HR)	Conductivity (BTU/HR-FT-F)	Sound Velocity (FT/SEC)
40.00000	5.2301378E-02	4.0625810E-02	1.6449620E+03
70.00000	5.4834472E-02	4.2473701E-02	1.6936218E+03
100.00000	5.7302310E-02	4.4276174E-02	1.7409220E+03
130.00000	5.9708821E-02	4.6036461E-02	1.7869707E+03
160.00000	6.2057765E-02	4.7757544E-02	1.8318622E+03
190.00000	6.4352726E-02	4.9442169E-02	1.8755795E+03
220.00000	6.6597095E-02	5.1092872E-02	1.9184964E+03
250.00000	6.8794071E-02	5.2711988E-02	1.9603783E+03
280.00000	7.0946667E-02	5.4301672E-02	2.0013840E+03
310.00000	7.3057709E-02	5.5863917E-02	2.0415562E+03
340.00000	7.5189265E-02	5.7479805E-02	2.0809727E+03
370.00000	7.7215247E-02	5.8979570E-02	2.1196467E+03
400.00000	7.9207939E-02	6.0458079E-02	2.1576276E+03
430.00000	8.1169245E-02	6.1916424E-02	2.1949514E+03
460.00000	8.3100948E-02	6.3355619E-02	2.2316510E+03
490.00000	8.5004721E-02	6.4776608E-02	2.2677568E+03
520.00000	8.6882134E-02	6.6180270E-02	2.3032967E+03
550.00000	8.8734662E-02	6.7567427E-02	2.3382965E+03
580.00000	9.0719997E-02	6.9036519E-02	2.3727301E+03
610.00000	9.2501848E-02	7.0372762E-02	2.4067596E+03
640.00000	9.4263621E-02	7.1695393E-02	2.4402858E+03
670.00000	9.6006740E-02	7.3005294E-02	2.4733478E+03
700.00000	9.7731386E-02	7.4302920E-02	2.5059737E+03
730.00000	9.9438497E-02	7.5588697E-02	2.5381302E+03
760.00000	1.0112877E-01	7.6863031E-02	2.5699332E+03
790.00000	1.0280286E-01	7.8126300E-02	2.6013974E+03
820.00000	1.0446140E-01	7.9378654E-02	2.6324367E+03
850.00000	1.0610497E-01	8.0621064E-02	2.6631143E+03
880.00000	1.0773413E-01	8.1853224E-02	2.6934425E+03
910.00000	1.0934943E-01	8.3075648E-02	2.7234330E+03
940.00000	1.1103629E-01	8.4303934E-02	2.7530968E+03
970.00000	1.1265272E-01	8.5506316E-02	2.7824444E+03
1000.00000	1.1422746E-01	8.6699878E-02	2.8114856E+03
1030.00000	1.1578082E-01	8.7884858E-02	2.8402299E+03
1060.00000	1.1732311E-01	8.9061480E-02	2.8686863E+03
1090.00000	1.1885461E-01	9.0229963E-02	2.8968531E+03
1120.00000	1.2037559E-01	9.1390511E-02	2.9247584E+03
1150.00000	1.2188632E-01	9.2543323E-02	2.9524100E+03
1180.00000	1.2338706E-01	9.3688588E-02	2.9797953E+03
1210.00000	1.2487803E-01	9.4826487E-02	3.0069311E+03
1240.00000	1.2635947E-01	9.5957195E-02	3.0338242E+03
1270.00000	1.2783161E-01	9.7080676E-02	3.0604310E+03
1300.00000	1.2929465E-01	9.8197693E-02	3.0869076E+03

Helium-Argon, M = 15.30 cont.

Temperature (F)	Enthalpy (BTU/LB)
40.00000	1.6214297E+02
70.00000	1.7187758E+02
100.00000	1.8161220E+02
130.00000	1.9134681E+02
160.00000	2.0108142E+02
190.00000	2.1081604E+02
220.00000	2.2055065E+02
250.00000	2.3028527E+02
280.00000	2.4001988E+02
310.00000	2.4975449E+02
340.00000	2.5948911E+02
370.00000	2.6922372E+02
400.00000	2.7895833E+02
430.00000	2.8869295E+02
460.00000	2.9842756E+02
490.00000	3.0816217E+02
520.00000	3.1789679E+02
550.00000	3.2763140E+02
580.00000	3.3736602E+02
610.00000	3.4710063E+02
640.00000	3.5683524E+02
670.00000	3.6656986E+02
700.00000	3.7630447E+02
730.00000	3.8603908E+02
760.00000	3.9577370E+02
790.00000	4.0550831E+02
820.00000	4.1524292E+02
850.00000	4.2497754E+02
880.00000	4.3471215E+02
910.00000	4.4444677E+02
940.00000	4.5418138E+02
970.00000	4.6391599E+02
1000.00000	4.7365061E+02
1030.00000	4.8338522E+02
1060.00000	4.9311983E+02
1090.00000	5.0285445E+02
1120.00000	5.1258906E+02
1150.00000	5.2232367E+02
1180.00000	5.3205829E+02
1210.00000	5.4179290E+02
1240.00000	5.5152752E+02
1270.00000	5.6126213E+02
1300.00000	5.7099674E+02

Helium-Argon

Molecular Weight = 15.83

Specific Heat at Constant Pressure = 0.31362 BTU/LB-R

Temperature (F)	Viscosity (LB/FT-HR)	Conductivity (BTU/HR-FT-F)	Sound Velocity (FT/SEC)
40.00000	5.2384618E-02	3.9396159E-02	1.6171903E+03
70.00000	5.4928517E-02	4.1190434E-02	1.6650286E+03
100.00000	5.7407116E-02	4.2940763E-02	1.7115303E+03
130.00000	5.9824291E-02	4.4650306E-02	1.7568015E+03
160.00000	6.2183763E-02	4.6321867E-02	1.8009351E+03
190.00000	6.4489079E-02	4.7958105E-02	1.8440127E+03
220.00000	6.6743604E-02	4.9561456E-02	1.8861067E+03
250.00000	6.8950516E-02	5.1134167E-02	1.9272815E+03
280.00000	7.1112809E-02	5.2678312E-02	1.9675949E+03
310.00000	7.3233298E-02	5.4195807E-02	2.0070987E+03
340.00000	7.5370145E-02	5.5761774E-02	2.0458399E+03
370.00000	7.7405684E-02	5.7219141E-02	2.0838609E+03
400.00000	7.9407606E-02	5.8655777E-02	2.1212006E+03
430.00000	8.1377829E-02	6.0072747E-02	2.1579943E+03
460.00000	8.3318152E-02	6.1471042E-02	2.1939743E+03
490.00000	8.5230263E-02	6.2851587E-02	2.2294706E+03
520.00000	8.7115747E-02	6.4215242E-02	2.2644104E+03
550.00000	8.8976092E-02	6.5562812E-02	2.2988193E+03
580.00000	9.0968306E-02	6.6992407E-02	2.3327207E+03
610.00000	9.2757737E-02	6.8289597E-02	2.3661364E+03
640.00000	9.4527012E-02	6.9573938E-02	2.3990867E+03
670.00000	9.6277033E-02	7.0845900E-02	2.4315906E+03
700.00000	9.8008596E-02	7.2105926E-02	2.4636656E+03
730.00000	9.9722451E-02	7.3354433E-02	2.4953284E+03
760.00000	1.0141931E-01	7.4591815E-02	2.5265945E+03
790.00000	1.0309984E-01	7.5818442E-02	2.5574783E+03
820.00000	1.0476467E-01	7.7034665E-02	2.5879936E+03
850.00000	1.0641441E-01	7.8240817E-02	2.6181532E+03
880.00000	1.0804964E-01	7.9437212E-02	2.6479694E+03
910.00000	1.0967089E-01	8.0624150E-02	2.6774536E+03
940.00000	1.1142182E-01	8.1818356E-02	2.7066166E+03
970.00000	1.1300326E-01	8.2985687E-02	2.7354687E+03
1000.00000	1.1457297E-01	8.4144452E-02	2.7640196E+03
1030.00000	1.1613127E-01	8.5294890E-02	2.7922787E+03
1060.00000	1.1767846E-01	8.6437221E-02	2.8202546E+03
1090.00000	1.1921483E-01	8.7571654E-02	2.8479557E+03
1120.00000	1.2074066E-01	8.8698389E-02	2.8753899E+03
1150.00000	1.2225620E-01	8.9817619E-02	2.9025648E+03
1180.00000	1.2376172E-01	9.0929526E-02	2.9294877E+03
1210.00000	1.2525745E-01	9.2034287E-02	2.9561654E+03
1240.00000	1.2674362E-01	9.3132070E-02	2.9826045E+03
1270.00000	1.2822046E-01	9.4223037E-02	3.0088113E+03
1300.00000	1.2968818E-01	9.5307343E-02	3.0347917E+03

Helium-Argon, M = 15.83 cont.

Temperature (F)	Enthalpy (BTU/LB)
40.00000	1.5671430E+02
70.00000	1.6612300E+02
100.00000	1.7553169E+02
130.00000	1.8494038E+02
160.00000	1.9434907E+02
190.00000	2.0375776E+02
220.00000	2.1316645E+02
250.00000	2.2257515E+02
280.00000	2.3198384E+02
310.00000	2.4139253E+02
340.00000	2.5080122E+02
370.00000	2.6020991E+02
400.00000	2.6961860E+02
430.00000	2.7902730E+02
460.00000	2.8843599E+02
490.00000	2.9784468E+02
520.00000	3.0725337E+02
550.00000	3.1666206E+02
580.00000	3.2607075E+02
610.00000	3.3547945E+02
640.00000	3.4488814E+02
670.00000	3.5429683E+02
700.00000	3.6370552E+02
730.00000	3.7311421E+02
760.00000	3.8252290E+02
790.00000	3.9193160E+02
820.00000	4.0134029E+02
850.00000	4.1074898E+02
880.00000	4.2015767E+02
910.00000	4.2956636E+02
940.00000	4.3897505E+02
970.00000	4.4838375E+02
1000.00000	4.5779244E+02
1030.00000	4.6720113E+02
1060.00000	4.7660982E+02
1090.00000	4.8601851E+02
1120.00000	4.9542720E+02
1150.00000	5.0483589E+02
1180.00000	5.1424459E+02
1210.00000	5.2365328E+02
1240.00000	5.3306197E+02
1270.00000	5.4247066E+02
1300.00000	5.5187935E+02

Helium-Argon

Molecular Weight = 27.53

Specific Heat at Constant Pressure = 0.18034 BTU/LB-R

Temperature (F)	Viscosity (LB/FT-HR)	Conductivity (BTU/HR-FT-F)	Sound Velocity (FT/SEC)
40.00000	5.2563842E-02	2.0434522E-02	1.2263050E+03
70.00000	5.5227557E-02	2.1402132E-02	1.2625304E+03
100.00000	5.7827260E-02	2.2347336E-02	1.2978423E+03
130.00000	6.0365858E-02	2.3271434E-02	1.3321712E+03
160.00000	6.2846258E-02	2.4175647E-02	1.3656374E+03
190.00000	6.5271322E-02	2.5061130E-02	1.3983029E+03
220.00000	6.7643847E-02	2.5928965E-02	1.4302225E+03
250.00000	6.9966537E-02	2.6780169E-02	1.4614451E+03
280.00000	7.2241997E-02	2.7615696E-02	1.4920145E+03
310.00000	7.4472722E-02	2.8436438E-02	1.5219700E+03
340.00000	7.6670221E-02	2.9253647E-02	1.5513471E+03
370.00000	7.8817021E-02	3.0045581E-02	1.5801783E+03
400.00000	8.0926015E-02	3.0825225E-02	1.6084927E+03
430.00000	8.2999207E-02	3.1593220E-02	1.6363173E+03
460.00000	8.5038497E-02	3.2350167E-02	1.6636765E+03
490.00000	8.7045687E-02	3.3096632E-02	1.6905931E+03
520.00000	8.9022481E-02	3.3833145E-02	1.7170378E+03
550.00000	9.0970492E-02	3.4560205E-02	1.7431798E+03
580.00000	9.2984234E-02	3.5334411E-02	1.7688870E+03
610.00000	9.4864927E-02	3.6032088E-02	1.7942259E+03
640.00000	9.6721845E-02	3.6722246E-02	1.8192119E+03
670.00000	9.8556091E-02	3.7405190E-02	1.8438594E+03
700.00000	1.0036871E-01	3.8081209E-02	1.8681817E+03
730.00000	1.0216070E-01	3.8750575E-02	1.8921914E+03
760.00000	1.0393299E-01	3.9413547E-02	1.9159002E+03
790.00000	1.0568648E-01	4.0070366E-02	1.9393192E+03
820.00000	1.0742201E-01	4.0721264E-02	1.9624588E+03
850.00000	1.0914040E-01	4.1366460E-02	1.9853287E+03
880.00000	1.1084239E-01	4.2006162E-02	2.0079381E+03
910.00000	1.1252871E-01	4.2640566E-02	2.0302957E+03
940.00000	1.1450619E-01	4.3315536E-02	2.0524098E+03
970.00000	1.1613465E-01	4.3935632E-02	2.0742382E+03
1000.00000	1.1775107E-01	4.4551214E-02	2.0959382E+03
1030.00000	1.1935579E-01	4.5162402E-02	2.1173569E+03
1060.00000	1.2094912E-01	4.5769313E-02	2.1385808E+03
1090.00000	1.2253134E-01	4.6372057E-02	2.1595364E+03
1120.00000	1.2410274E-01	4.6970738E-02	2.1803396E+03
1150.00000	1.2566359E-01	4.7565458E-02	2.2009961E+03
1180.00000	1.2721415E-01	4.8156313E-02	2.2214116E+03
1210.00000	1.2875466E-01	4.8743396E-02	2.2415411E+03
1240.00000	1.3028537E-01	4.9326796E-02	2.2616897E+03
1270.00000	1.3180649E-01	4.9906596E-02	2.2815621E+03
1300.00000	1.3331826E-01	5.0482880E-02	2.3012529E+03

Helium-Argon, M = 27.53 cont.

Temperature (F)	Enthalpy (BTU/LB)
40.00000	9.0112148E+01
70.00000	9.5522231E+01
100.00000	1.0093231E+02
130.00000	1.0634240E+02
160.00000	1.1175248E+02
190.00000	1.1716256E+02
220.00000	1.2257265E+02
250.00000	1.2798273E+02
280.00000	1.3339281E+02
310.00000	1.3880290E+02
340.00000	1.4421298E+02
370.00000	1.4962306E+02
400.00000	1.5503315E+02
430.00000	1.6044323E+02
460.00000	1.6585331E+02
490.00000	1.7126340E+02
520.00000	1.7667348E+02
550.00000	1.8208356E+02
580.00000	1.8749364E+02
610.00000	1.9290373E+02
640.00000	1.9831381E+02
670.00000	2.0372389E+02
700.00000	2.0913398E+02
730.00000	2.1454406E+02
760.00000	2.1995414E+02
790.00000	2.2536423E+02
820.00000	2.3077431E+02
850.00000	2.3618439E+02
880.00000	2.4159448E+02
910.00000	2.4700456E+02
940.00000	2.5241464E+02
970.00000	2.5782473E+02
1000.00000	2.6323481E+02
1030.00000	2.6864489E+02
1060.00000	2.7405497E+02
1090.00000	2.7946506E+02
1120.00000	2.8487514E+02
1150.00000	2.9028522E+02
1180.00000	2.9569531E+02
1210.00000	3.0110539E+02
1240.00000	3.0651547E+02
1270.00000	3.1192556E+02
1300.00000	3.1733564E+02

Helium-Argon

Molecular Weight = 29.70

Specific Heat at Constant Pressure = 0.16716 BTU/LB-R

Temperature (F)	Viscosity (LB/FT-HR)	Conductivity (BTU/HR-FT-F)	Sound Velocity (FT/SEC)
40.00000	5.2418661E-02	1.8071935E-02	1.1806560E+03
70.00000	5.5089766E-02	1.8936920E-02	1.2155311E+03
100.00000	5.7697317E-02	1.9781982E-02	1.2495304E+03
130.00000	6.0244079E-02	2.0608217E-02	1.2825314E+03
160.00000	6.2732833E-02	2.1416669E-02	1.3148018E+03
190.00000	6.5166339E-02	2.2208326E-02	1.3462513E+03
220.00000	6.7547299E-02	2.2984125E-02	1.3769827E+03
250.00000	6.9878341E-02	2.3744946E-02	1.4070430E+03
280.00000	7.2162005E-02	2.4491622E-02	1.4364745E+03
310.00000	7.4400728E-02	2.5224934E-02	1.4653149E+03
340.00000	7.6602596E-02	2.5952060E-02	1.4935985E+03
370.00000	7.8757404E-02	2.6659758E-02	1.5213564E+03
400.00000	8.0874035E-02	2.7356255E-02	1.5486168E+03
430.00000	8.2954484E-02	2.8042132E-02	1.5754056E+03
460.00000	8.5000641E-02	2.8717935E-02	1.6017465E+03
490.00000	8.7014303E-02	2.9384180E-02	1.6275511E+03
520.00000	8.8997171E-02	3.0041350E-02	1.6531695E+03
550.00000	9.0950857E-02	3.0689903E-02	1.6782902E+03
580.00000	9.2953808E-02	3.1376622E-02	1.7030405E+03
610.00000	9.4841908E-02	3.1999396E-02	1.7274362E+03
640.00000	9.6705728E-02	3.2615263E-02	1.7514921E+03
670.00000	9.8546407E-02	3.3224512E-02	1.7752220E+03
700.00000	1.0036503E-01	3.3827417E-02	1.7986390E+03
730.00000	1.0216262E-01	3.4424234E-02	1.8217549E+03
760.00000	1.0394016E-01	3.5015209E-02	1.8445812E+03
790.00000	1.0569856E-01	3.5600570E-02	1.8671284E+03
820.00000	1.0743871E-01	3.6180539E-02	1.8894066E+03
850.00000	1.0916143E-01	3.6755321E-02	1.9114252E+03
880.00000	1.1086752E-01	3.7325114E-02	1.9331929E+03
910.00000	1.1255773E-01	3.7890104E-02	1.9547183E+03
940.00000	1.1456435E-01	3.8502097E-02	1.9760392E+03
970.00000	1.1619396E-01	3.9053187E-02	1.9970732E+03
1000.00000	1.1781154E-01	3.9600255E-02	2.0179173E+03
1030.00000	1.1941741E-01	4.0143436E-02	2.0385482E+03
1060.00000	1.2101187E-01	4.0662804E-02	2.0589725E+03
1090.00000	1.2259524E-01	4.1218466E-02	2.0791961E+03
1120.00000	1.2416778E-01	4.1750517E-02	2.0992249E+03
1150.00000	1.2572976E-01	4.2279046E-02	2.1190544E+03
1180.00000	1.2729145E-01	4.2804138E-02	2.1387199E+03
1210.00000	1.2882309E-01	4.3325877E-02	2.1581964E+03
1240.00000	1.3035492E-01	4.3844340E-02	2.1774987E+03
1270.00000	1.3187716E-01	4.4359603E-02	2.1966314E+03
1300.00000	1.3339004E-01	4.4871739E-02	2.2155988E+03

Helium-Argon, M = 29.70 cont.

Temperature (F)	Enthalpy (BTU/LB)
40.00000	8.3528196E+01
70.00000	8.8542997E+01
100.00000	9.3557798E+01
130.00000	9.8572599E+01
160.00000	1.0358740E+02
190.00000	1.0860220E+02
220.00000	1.1361700E+02
250.00000	1.1863180E+02
280.00000	1.2364660E+02
310.00000	1.2866141E+02
340.00000	1.3367621E+02
370.00000	1.3869101E+02
400.00000	1.4370581E+02
430.00000	1.4872061E+02
460.00000	1.5373541E+02
490.00000	1.5875021E+02
520.00000	1.6376501E+02
550.00000	1.6877981E+02
580.00000	1.7379461E+02
610.00000	1.7880941E+02
640.00000	1.8382422E+02
670.00000	1.8883902E+02
700.00000	1.9385382E+02
730.00000	1.9886862E+02
760.00000	2.0388342E+02
790.00000	2.0889822E+02
820.00000	2.1391302E+02
850.00000	2.1892782E+02
880.00000	2.2394262E+02
910.00000	2.2895742E+02
940.00000	2.3397223E+02
970.00000	2.3898703E+02
1000.00000	2.4400183E+02
1030.00000	2.4901663E+02
1060.00000	2.5403143E+02
1090.00000	2.5904623E+02
1120.00000	2.6406103E+02
1150.00000	2.6907583E+02
1180.00000	2.7409063E+02
1210.00000	2.7910543E+02
1240.00000	2.8412024E+02
1270.00000	2.8913504E+02
1300.00000	2.9414984E+02

APPENDIX B.
EXPERIMENT

Apparatus

A schematic diagram of the experiment is shown in Fig. B1. The helium and helium-argon mixtures were bought from manufacturers in high pressure bottles. The air was obtained from a large storage tank that was replenished by a compressor. Two regulators were used to reduce and stabilize the pressure. A Brooks rotometer was used to obtain a rough measurement of the flow rate. A Bourdon tube Heise gage measured the pressure just downstream of the rotometer. A small tank constructed to mix the gas, and instrumented with a thermocouple measured the inlet stagnation temperature. A sketch of the test section from the inlet to just below the outlet mixing tank, and displaying the location of thermocouples, pressure taps, electrodes, and voltage taps is shown in Fig. B2.

Power was measured using a Fluke differential voltmeter and Weston ammeter in the same manner as Perkins et al. [27]. Whenever possible the power supply described by Perkins et al. [27] was used. When it did not supply sufficient power an a.c. Lincoln welder (Model TM-500/500) was used. To determine a power factor when the welder was used, the power measured with a Weston watt meter was compared to that calculated from voltage (Fluke voltmeter)

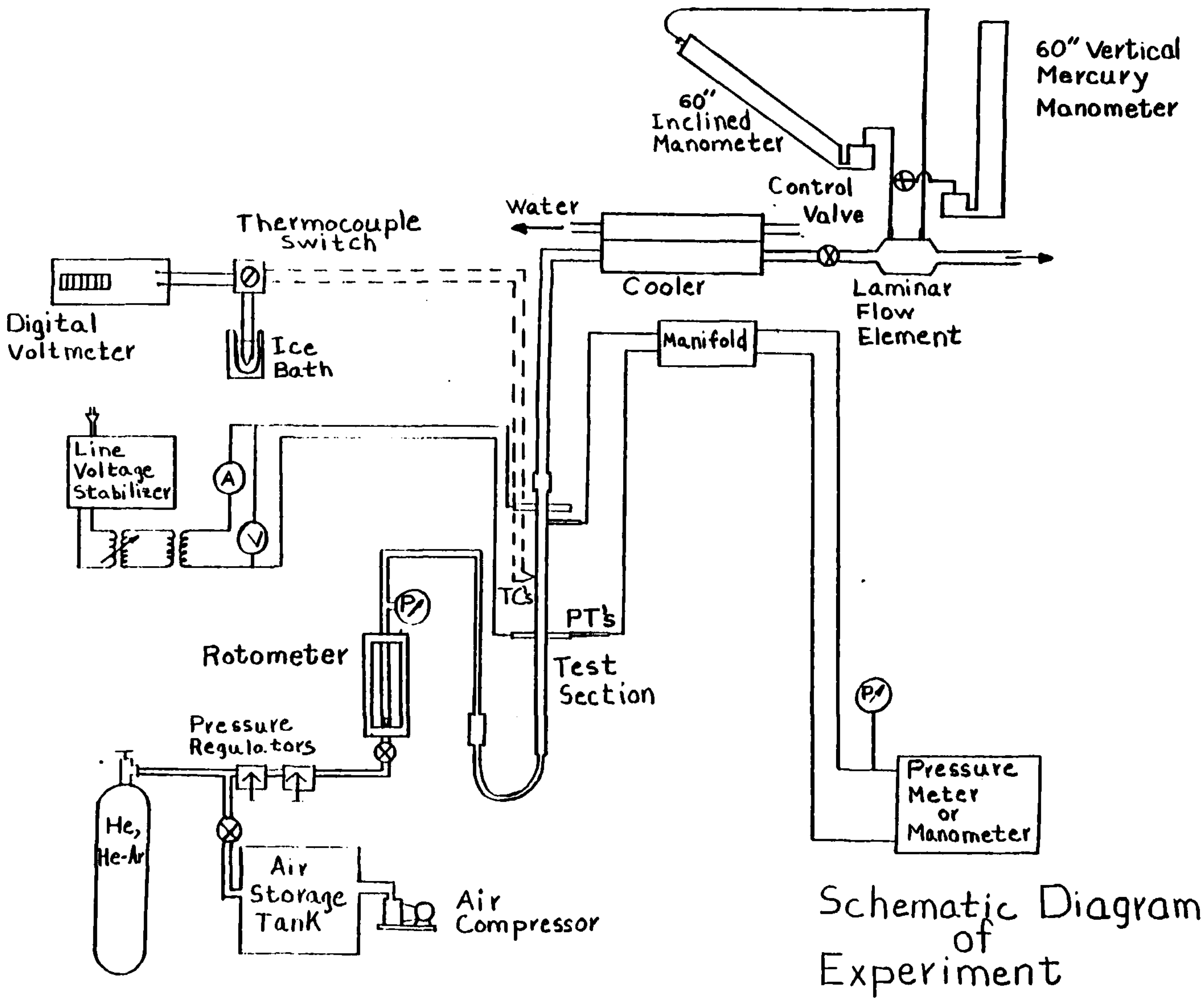

60" Vertical
Mercury
Manometer
60"
Inclined
Manometer
Control
Valve
Water
Thermocouple
Switch
Cooler
Laminar
Flow
Element
Digital
Voltmeter
Ice
Bath
Manifold
Line
Voltage
Stabilizer
A
V
TC's
PT's
Rotometer
Test
Section
Pressure
Regulators
He,
He-Ar
Air
Storage
Tank
Air
Compressor
Pressure
Meter
or
Manometer
Schematic Diagram
of
Experiment

Fig. B1.

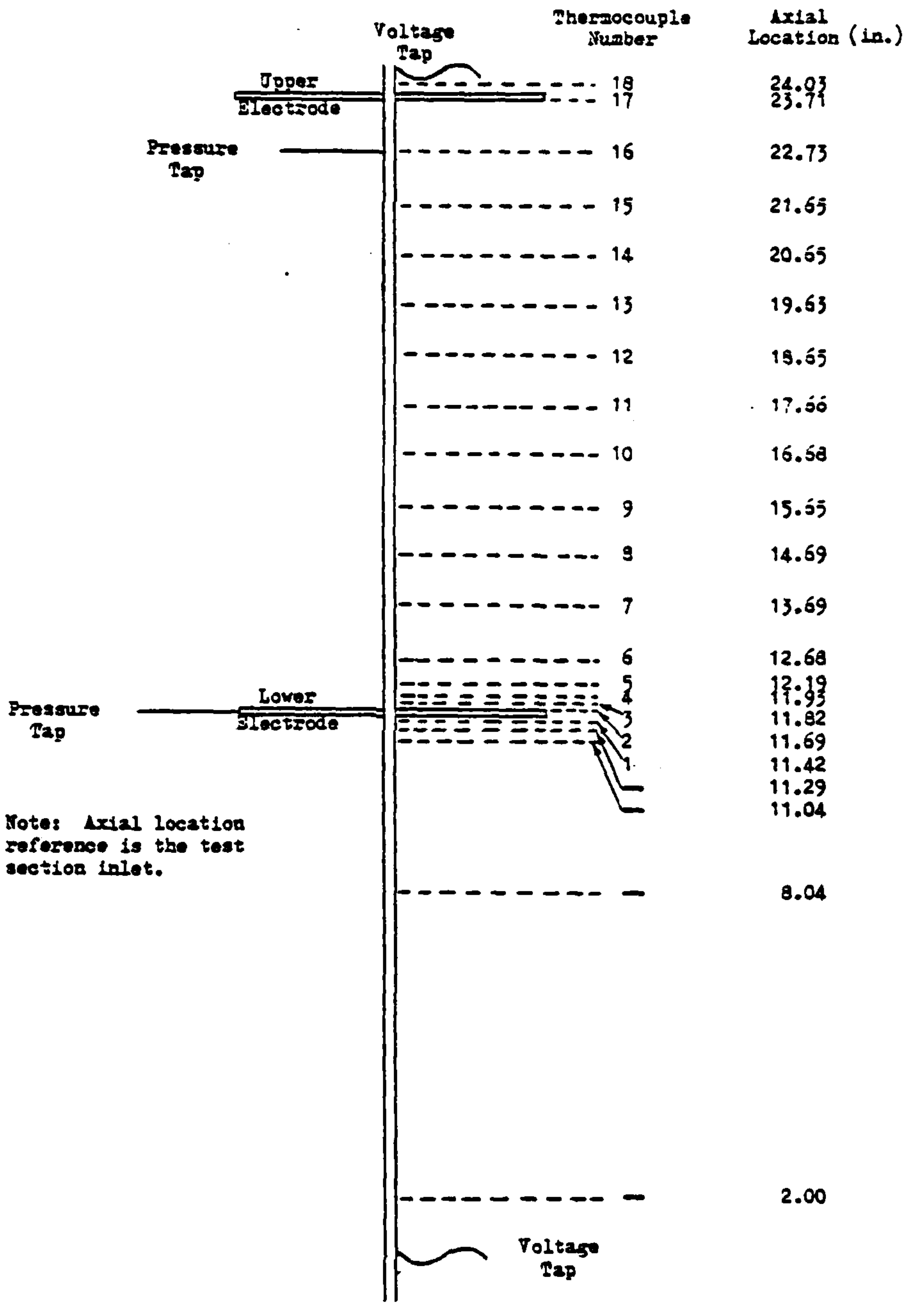


Fig. B2. Diagram of test section.

and current (Weston ammeter) measurements. A power factor of 1.0 was used since the two measurements agreed within 3.3 percent.

Thermocouple output was measured with a Hewlett Packard digital voltmeter. An ice bath was used as a reference for all of the thermocouples. Thermocouples were selected for measurement using a manual switch. The numbered thermocouples on Fig. B2 were used in the computer program that reduced the experimental data for the heated runs. This computer program is described by a number of people [30,31,32,44]. The unnumbered thermocouples were used to determine the amount of preheating of the gas before it entered the heated section.

Pressure drop in the test section was measured with Meriam 60 inch vertical water or mercury manometers. Inlet static pressure was measured with a Bourdon tube Heise gage.

After the gas passed through the test section, it was cooled by a chilled water counterflow heat exchanger. The valve used to control the flow rate was located just downstream of the heat exchanger. The heat exchanger was necessary in order that a Meriam laminar flow element could be used. The laminar flow element was used to obtain an accurate measurement of the flow rate. A Meriam 60 inch inclined water manometer with a 10 inch range was used to measure pressure drop across the laminar flow

element. The temperature of the gas in the flow element was measured with a thermocouple, and the pressure was measured with a Meriam 60 inch vertical mercury manometer. The accuracies of the instruments used in this investigation are listed in appendix C (Table C1).

Procedure

Before any experimental runs with gas flow were performed, the test section was heated without flow in order that the heat lost to the environment and the resistance of the test section could be determined. These items are discussed in detail in the following two sections.

The system was purged and all of the instruments zeroed before each set of experimental runs. The purging was done by pressurizing the system to approximately 100 psig with the gas to be used. The system was then allowed to blow down to approximately 10 psig. This sequence was performed four times.

The desired inlet Reynolds number was established by adjusting the pressure level and mass flow rate. Before power was supplied to the test section, measurements were taken so that calculation of the adiabatic friction coefficient was possible. The measured adiabatic friction coefficients were compared to the Drew, Koo, and McAdams correlation [34] (equation 11), and agreement ensured that the pressure measurements, mass flow rate measurements, and mixture molecular weights were correct.

The test section was then heated to the desired level. Since a small period of time elapsed while the thermocouples were manually recorded, pressure drop, pressure level, voltage, current, and mass flow rate measurements were taken before and after the thermocouple measurements. The average of the two measurements was used for data reduction. The inlet Reynolds number was maintained approximately constant while the test section wall temperature was varied by varying the power input. Measurements were taken for a number of different power inputs.

Heat Loss Calibration

In order to calculate the heat transfer coefficient, the heat addition to the gas, q'_{gas}, must be determined. If an energy balance for a small section of the tube is performed, the result is:

$$q'_{gas} = q'_{gen} - (q'_{cond} + q'_{loss}). \tag{B1}$$

The heat generated in the small section of the tube, q'_{gen}, is:

$$q'_{gen} = I^2R'. \tag{B2}$$

The current was measured, and the calculation of the resistance per unit length is discussed in the next section. The axial heat loss due to conduction is:

$$q'_{cond} = -K\ A_{cs}\ d^2T_w/dx^2. \tag{B3}$$

The second derivative was determined using a numerical parabolic fit described by McEligot [31]. The variation of thermal conductivity with temperature for Hastelloy-X

was determined from data supplied by the manufacturer [46].

$$K = [5.1 + (0.00622)(T)](\text{Btu/hr-ft-F}) \qquad (B4)$$
$$(T \text{ in degrees Fahrenheit})$$

To determine the heat loss, q'_{loss}, the test section was heated at different levels without gas flow. A program described by Coon [32] was used to calculate the heat loss at each thermocouple. The heat loss was determined as a function of the tube wall and environment temperature difference. The environment temperature was measured with a thermocouple a few inches away from the test section. Figures B3, B4, B5, and B6 show the results for each thermocouple (thermocouple 4 is not included). Except for thermocouple three and four, the data for each thermocouple was fitted with an equation of the form:

$$q'_{loss} = C_1(T_w-T_\infty) + C_2(T_w-T_\infty)^2 + C_3(T_w-T_\infty)^3 \quad (\text{Btu/hr-ft}) \qquad (B5)$$
$$(T_w - T_\infty \text{ in degrees Fahrenheit})$$

The numerical values of C_1, C_2, and C_3 are listed below.

Thermocouple	C_1	C_2	C_3
2	2.43E+00	9.43E-03	-2.53E-05
5	1.22E-01	1.84E-04	-1.64E-08
6	9.83E-02	2.30E-04	-6.57E-08
7	8.84E-02	1.66E-04	-3.79E-09
8	8.30E-02	1.35E-04	3.07E-08
9	8.16E-02	1.03E-04	6.04E-08
10	7.89E-02	1.12E-04	4.96E-08
11	7.70E-02	8.82E-05	7.13E-08
12	7.40E-02	1.03E-04	5.50E-08
13	7.54E-02	8.08E-05	7.59E-08
14	7.31E-02	9.77E-05	5.73E-08
15	8.09E-02	8.07E-05	7.46E-08
16	1.18E-01	1.59E-04	5.59E-08
17	2.76E-01	1.14E-03	1.19E-06

The data for thermocouple three was fitted with a straight line determined using the method of least squares.

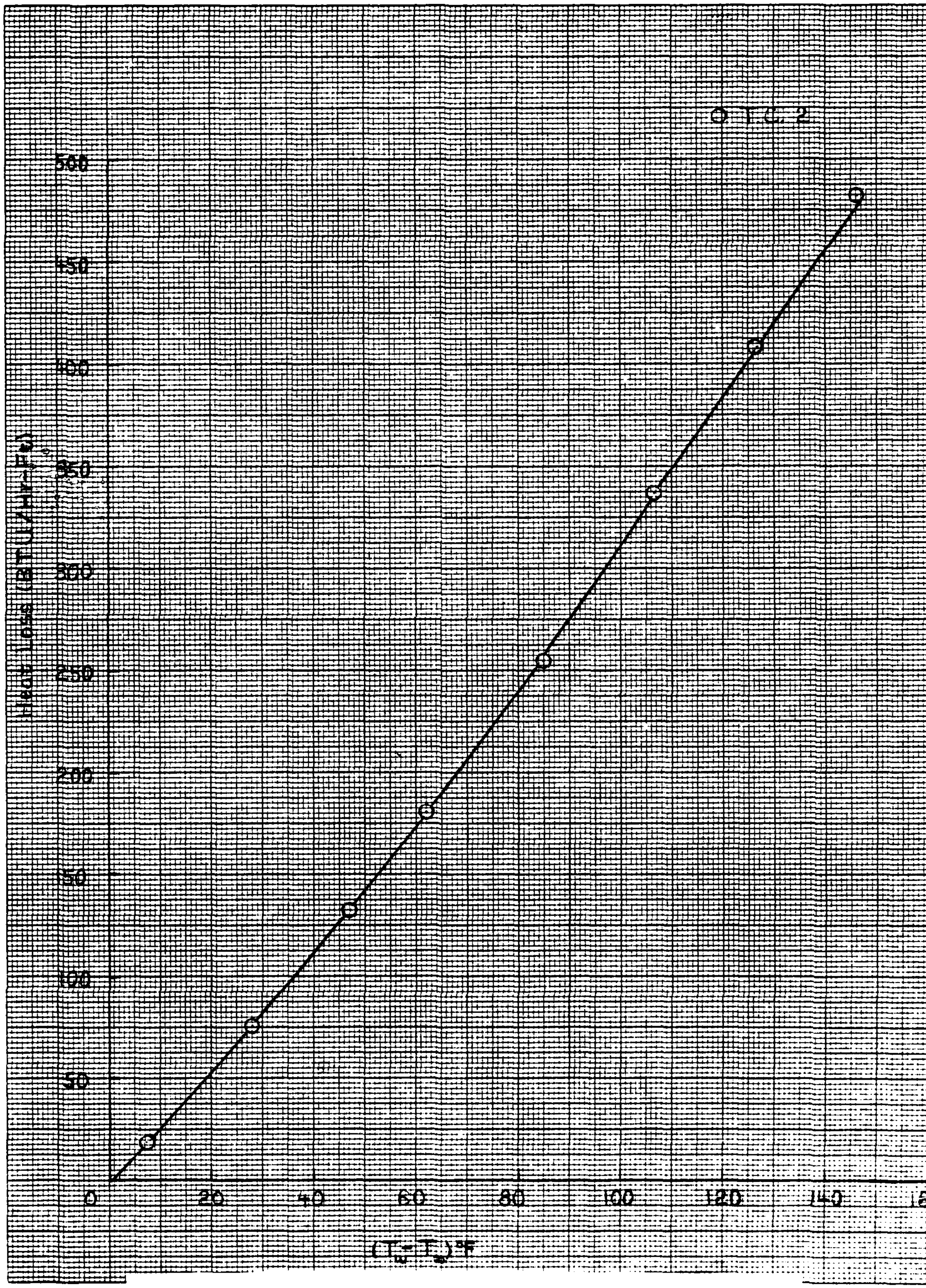


Fig. B3. Heat loss calibration for thermocouple 2.

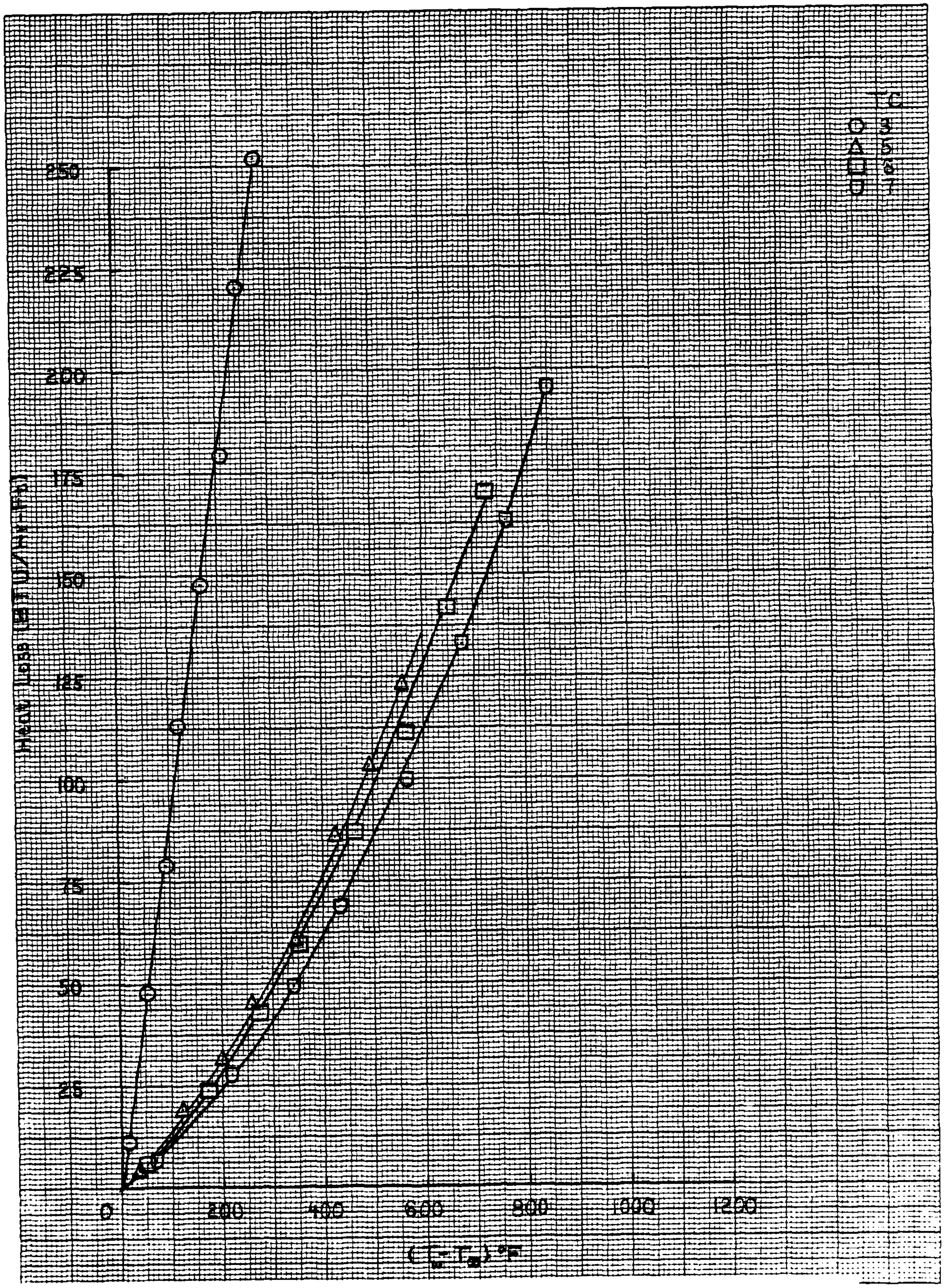
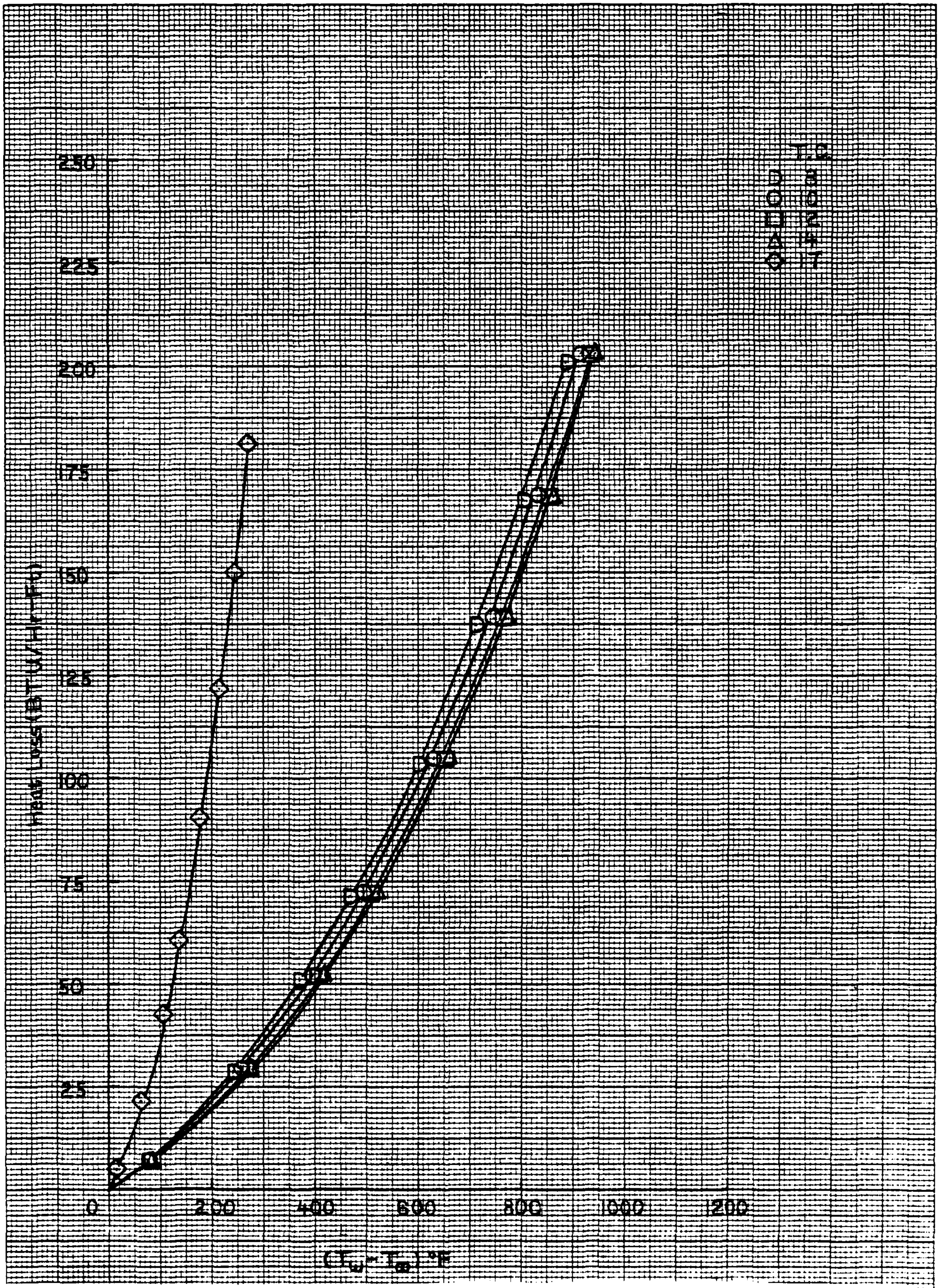


Fig. B4. Heat loss calibration for thermocouples 3, 5, 6, and 7.



K+E 10 X 10 TO THE CENTIMETER 46 1513
18 X 25 CM. MADE IN U.S.A.
KEUFFEL & ESSER CO.

Fig. B5. Heat loss calibration for thermocouples 8, 10, 12, 14, and 17.

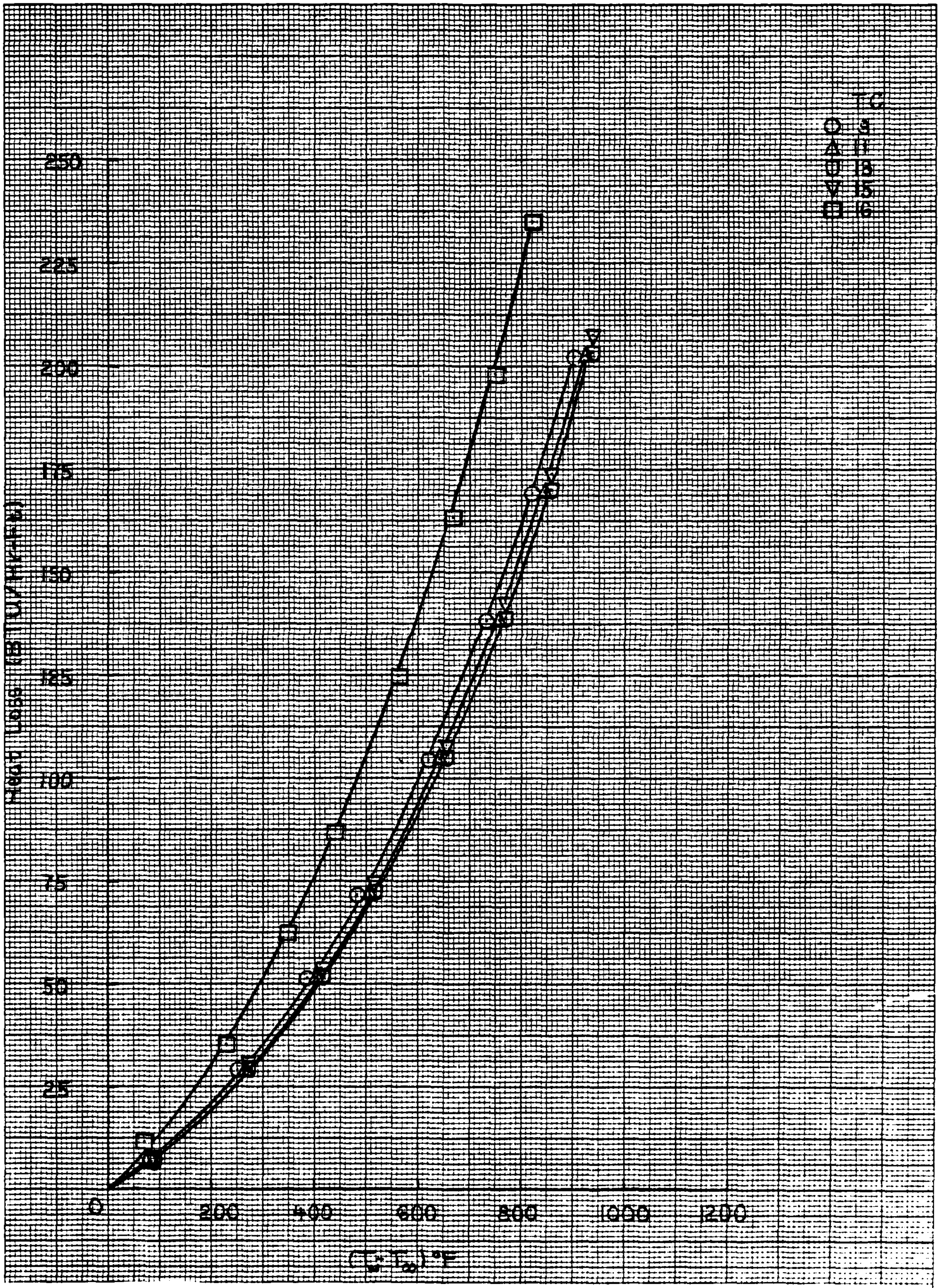


Fig. B6. Heat loss calibration for thermocouples 9, 11, 13, 15, and 16.

$$q'_{loss}(T.C.\ 3) = 0.91(T_w - T_\infty) - 2.20(Btu/hr\text{-}ft) \quad (B6)$$
$$(T_w - T_\infty \text{ in degrees Fahrenheit})$$

The data for thermocouple four was scattered and a representative curve could not be fitted. For this reason the heat loss at this thermocouple was neglected. This introduced only a small error since the heat loss for thermocouple four, even at the highest heating rates, was less than five percent of the heat added to the gas. The fitted curves are also shown on Figures B3, B4, B5, and B6.

Measurement of Test Section Resistance

The variation of resistance with temperature was measured by heating the test section without gas flow in the same manner as was done for the heat loss calibration. Using the thermocouple wires as voltage taps, a measurement of the voltage drop between thermocouple 14 and the lowermost thermocouple on the tube was taken. Another measurement of the voltage drop between thermocouple 12 and the lowermost thermocouple was taken. The difference between these two measurements gave the voltage drop between thermocouples 12 and 14. The section of the tube between thermocouples 12 and 14 was used since the wall temperature for this length was approximately constant.

For a particular power setting the voltage drop discussed in the previous paragraph, the current, and the average of the temperatures at thermocouples 12, 13, and

14 were recorded. Using these measurements the resistance per unit length was determined as a function of temperature. The results are shown on Fig. B7. Also shown on Fig. B7 is the line that was used to approximate the variation of resistance with temperature.

$$R' = [3.98 \times 10^{-4}(T) + 4.745] \ (m\Omega/in) \qquad (B7)$$
(T in degrees Fahrenheit)

<u>Meriam Laminar Flow Element Calibration</u>

The laminar flow element was calibrated using a Parkinson-Cowan Type D1 positive displacement flow meter as a standard. It is specified to have 1/2 percent accuracy at ambient conditions and was calibrated by Tucson Gas and Electric before being used. Meriam [45] suggests the following equation for the laminar flow element:

$$\Delta P = A'Q\mu L/D^4 + B'\rho Q^2/D^4. \qquad (B8)$$

A' and B' are the constants to be determined by calibration. Since the length, L, and the hydraulic diameter, D, of the laminar flow element passages remain constant, they can be incorporated into new calibration constants, A and B.

$$A = A'L/D^4 \qquad B = B'/D^4$$

Equation B8 now becomes:

$$\Delta P = AQ\mu + B\rho Q^2. \qquad (B9)$$

If this equation is solved for Q the result is:

$$Q = [-A\mu/B + \sqrt{(A\mu/B)^2 + 4\rho\Delta P/B}]/2\rho. \qquad (B10)$$

If both sides of this equation are multiplied by the density, ρ, the result is:

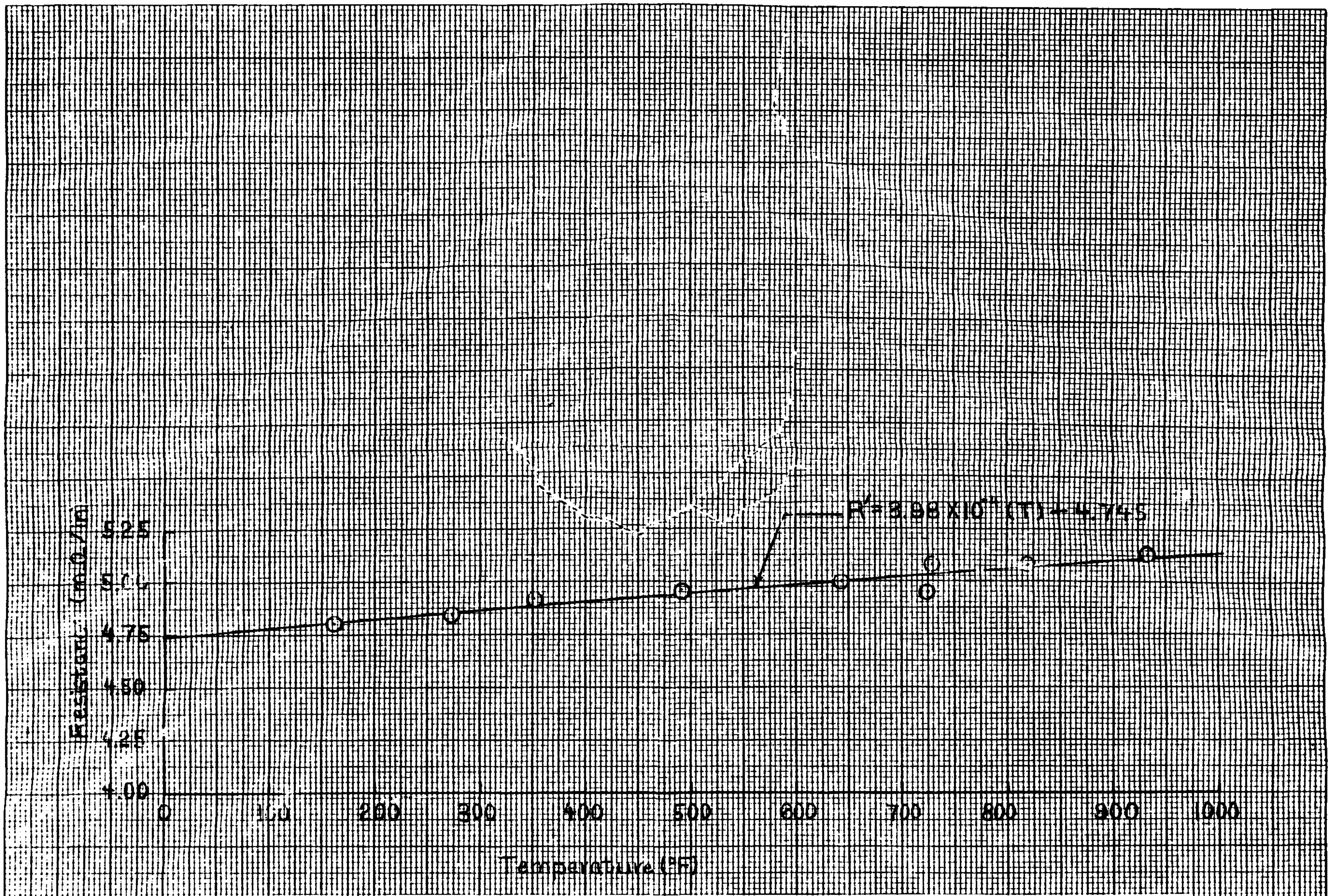


Fig. B7. Variation of test section resistance with respect to temperature.

$$\dot{m} = \rho Q = 1/2[-A\mu/B + \sqrt{(A\mu/B)^2 + 4\rho\Delta P/B}]. \qquad \text{(B11)}$$

Mass flow rate measurements were taken simultaneously with the positive displacement flow meter and the laminar flow element. Both air and helium were used. These gases bound the range of helium-argon mixture molecular weights that were used. From these measurements, A and B were determined so that the maximum difference between the positive displacement flow meter measurements and the laminar flow element measurements was 1.5 percent. The numerical values of A and B were 1375 and 672, respectively, if the parameters in equation B11 have the following units.

m - lb/sec
μ - lb/hr-ft
ρ - lb/ft^3
ΔP - inches of water

APPENDIX C
Uncertainty Analysis

An analysis to determine the uncertainty of the results calculated from the measured experimental data was performed. The uncertainties of the directly measured quantities were determined from manufacturers' specifications and experience. Table C1 lists the uncertainties of the instruments used in this investigation. The error propagated to the calculated results from the uncertainties in the measured quantities was determined using a method described by Bottaccini [47]. The general equation used was

$$\sigma_Z^2 = \left(\frac{\partial Z}{\partial Y_1}\right)^2 \sigma_{Y_1}^2 + \left(\frac{\partial Z}{\partial Y_2}\right)^2 \sigma_{Y_2}^2 + \ldots + \left(\frac{\partial Z}{\partial a_1}\right)^2 \sigma_{a_1}^2 + \left(\frac{\partial Z}{\partial a_2}\right)^2 \sigma_{a_2}^2 + \ldots \tag{C1}$$

σ_x is the variance or standard deviation of the xth quantity. Z is the calculated quantity, and Y_i and a_i are the measured values and system parameters used to calculate Z.

To illustrate the above technique, a simple example will be done. The power supplied to the tube can be determined using the relation (assuming a power factor of one)

$$P = E\ I. \tag{C2}$$

If equation C1 is applied, the error or variance in the power caused by uncertainties in the voltage and current measurements is

$$\sigma_P = \sqrt{(I)^2\sigma_E^2 + (E)^2\sigma_I^2}. \quad (C3)$$

The result can be presented in the following form so that the percent of uncertainty can easily be determined.

$$\sigma_P/P = \sqrt{(\sigma_E/E)^2 + (\sigma_I/I)^2} \quad (C4)$$

TABLE C1
Uncertainties of Measured Values

Measured quantity	Instrument	Uncertainty
Current	Weston 370 AC/DC ammeter	±0.25% of full scale
Voltage	Fluke 883AB differential voltmeter	±0.1% of input
Mass flow rate	Meriam 50MH10-1 laminar flow element	±1.5% of flow rate
Wall and inlet bulk temperature	Premium grade chromel-alumel thermocouples	±2°F, 3/8% of reading above 535°F
Thermocouple location Pressure tap location	Gaertner M911 Cathetometer	±0.1mm
Diameter	Manufacturers' specifications	±0.001 in.
Pressure	12 inch Heise gage	±0.15 psi
Pressure drop	60" Meriam 30EB25 vertical H_2O manometer	±0.05 in-H_2O
	60" Meriam 30EB25 vertical Hg manometer	±0.05 in-Hg

Table C2 lists the percentage uncertainty in the measured bulk Nusselt numbers for two representative helium-argon runs. The dominant uncertainty in the bulk Nusselt number is the bulk stagnation temperature. For convenience no uncertainty was included for the gas properties. The values used were assumed to be precise.

TABLE C2
Percentage Uncertainties in the Measured Bulk Nusselt Numbers of Helium-Argon

Run	126H	131H
Molecular weight	15.30	15.30
Re_i	56100	54700
$(T_w/T_b)_{MAX}$	1.17	1.77
x/D	Percentage Uncertainty	
1.17	13	10
2.07	8	6
4.14	6	4
8.13	5	3
24.52	4	3
40.79	4	3
56.88	4	3

APPENDIX D
Helium-Argon Experimental Data

The headings and their definitions used in the listing of the adiabatic friction data are below.

Heading	Definition
Run	Experiment run number
Date	Date on which experimental run was made
Gas	Gas used in the experiment
Molec. wt.	Molecular weight
T_i	Inlet mixer temperature
$\dot{m}$	Gas flow rate
Re_i	Inlet Reynolds number
P_1	Static pressure at inlet pressure tap
P_2	Static pressure at outlet pressure tap
Static $Mach_1$	Static mach number at inlet pressure tap
Static $Mach_2$	Static mach number at outlet pressure tap
f_{ad}	Adiabatic friction factor

Table D-1 HELIUM-ARGON ADIABATIC FRICTION FACTOR DATA

Run	Date	Gas	Molec. Wt.	T_1 (^oF)	$\dot{m}$ (lb/hr)	Re_1	P_1 (psia)	P_2 (psia)	Static $Mach_1$	Static $Mach_2$	f_{ad}
77A	8/27/75	He	4.003	71.5	3.8	9950	105.4	104.7	0.0521	0.0524	0.00796
81A	8/30/75	He	4.003	72.7	3.7	9660	102.0	101.3	0.0524	0.0527	0.00817
83A	8/30/75	He	4.003	78.0	12.7	32900	80.1	71.6	0.228	0.255	0.00582
85A	9/10/75	He	4.003	75.5	12.5	32500	76.4	67.6	0.235	0.265	0.00586
86A	9/12/75	He-Ar	15.83	72.3	12.3	27800	97.7	96.1	0.0916	0.0931	0.00619
87A	9/12/75	He-Ar	15.83	72.7	24.6	55400	76.0	68.6	0.233	0.258	0.00509
88A	10/ 8/75	He-Ar	15.83	73.0	26.5	59700	74.6	65.4	0.255	0.290	0.00515
91A	10/ 8/75	He-Ar	15.83	72.7	27.7	62400	83.0	74.4	0.240	0.267	0.00503
92A	10/13/75	He-Ar	15.83	72.3	14.1	31700	95.8	93.8	0.106	0.109	0.00607
95A	10/13/75	He-Ar	15.83	72.7	14.1	31800	95.5	93.5	0.107	0.110	0.00597
96A	10/20/75	He-Ar	15.83	72.7	38.3	86100	96.3	82.3	0.285	0.331	0.00468
99A	11/17/75	He-Ar	29.70	70.0	41.8	94200	74.5	63.1	0.293	0.344	0.00458
100A	11/17/75	He-Ar	29.70	70.0	29.9	67300	91.7	87.3	0.172	0.180	0.00493
101A	1/28/76	He-Ar	29.70	71.0	37.0	83200	110.5	105.5	0.176	0.185	0.00447
106A	1/28/76	He-Ar	29.70	72.7	13.9	31100	93.0	91.9	0.0790	0.0799	0.00614
110A	1/29/76	He-Ar	29.70	67.0	14.3	32400	93.4	92.2	0.0810	0.0819	0.00585
113A	2/ 6/76	He-Ar	27.53	73.0	13.5	30200	89.8	88.7	0.0828	0.0838	0.00588
114A	2/ 6/76	He-Ar	27.53	74.0	34.7	77500	110.2	105.0	0.173	0.181	0.00476
115A	2/21/76	He-Ar	27.53	70.5	43.8	98300	96.7	87.1	0.247	0.273	0.00457
121A	2/21/76	He-Ar	27.53	71.0	43.6	97800	95.3	85.5	0.249	0.277	0.00459
122A	3/ 1/76	He-Ar	15.30	70.5	24.7	55700	77.5	70.2	0.232	0.256	0.00497
123A	3/ 1/76	He-Ar	15.30	70.5	14.2	32200	92.8	90.7	0.113	0.115	0.00568

The headings and their definitions used in the listing of the heated flow data are below. The headings that are self-explanatory, or that were used in the listing of the adiabatic friction data are not included.

Heading	Definition
TIN	Inlet mixer temperature
TOUT	Outlet mixer temperature
I	Alternating current
E	Voltage drop between voltage taps
TC	Thermocouple number
X/D	Corresponds to x/D in text
TW	Inside tube wall temperature
TW/TB	Wall-to-bulk temperature ratio
QGAS	Wall heat flux
Q^+	Non-dimensional heat flux parameter. Corresponds to q^+ in text.
PT	Pressure tap: 1-inlet, 2-outlet
TB	Bulk static temperature

RUN 89HP, DATE 10/08/75, GAS HE-AR, MOLECULAR WT. = 15.83
TIN = 72.8 F, TOUT = 308.7 F, MASS FLOW RATE = 24.1 LB/HR, I = 100.2 AMPS, E = 5.765 VOLTS
PR,IN = .418, GR/RESQ = .725E-04, MACH(2) = .217, MACH(16) = .305, T,SURR = 75.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	130.0	1.122	54772.	.062	250.36	57728.3	.001195
3	1.2	194.6	1.239	54528.	.105	116.28	55763.4	.001144
4	2.1	224.4	1.290	54334.	.030	101.37	59976.7	.001231
5	4.1	256.0	1.336	53891.	.020	86.42	60655.1	.001245
6	8.1	297.5	1.369	53073.	.018	76.37	60965.9	.001251
7	16.4	319.1	1.374	51479.	.016	71.00	61182.5	.001256
8	24.5	348.4	1.375	50042.	.018	66.62	61233.2	.001257
9	32.4	366.7	1.360	48742.	.017	65.88	61329.4	.001259
10	40.8	390.0	1.351	47451.	.019	63.36	61308.0	.001258
11	48.7	407.1	1.336	46315.	.019	63.70	61400.4	.001260
12	56.3	430.6	1.330	45229.	.021	61.64	61359.4	.001259
13	64.8	448.1	1.318	44229.	.022	61.42	61417.9	.001261
14	73.1	472.0	1.313	43249.	.025	59.52	61349.9	.001259
15	81.3	487.3	1.298	42351.	.027	60.07	61282.7	.001258
16	90.1	493.5	1.259	41452.	.044	63.05	60274.0	.001237
17	98.0	435.6	1.165	40749.	.198	92.24	52321.3	.001074

PT	X/D	STATIC PRESS. (PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	80.3	1.10	65.5	-.516E-02
2	90.1	67.8	1.27	291.4	.199E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
48128.	36951.	.00554

RUN 90HP, DATE 10/08/75, GAS HE-AR, MOLECULAR WT. = 15.83
TIN = 72.8 F, TOUT = 547.4 F, MASS FLOW RATE = 25.1 LB/HR, I = 142.7 AMPS, E = 8.520 VOLTS
PR,IN = .418, GR/RESQ = .166E-03, MACH(2) = .204, MACH(16) = .340, T,SURR = 79.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	199.2	1.248	56716.	.073	232.29	116516.4	.002300
3	1.2	325.0	1.472	56221.	.105	115.33	114231.8	.002255
4	2.1	383.0	1.568	55827.	.031	101.32	122912.0	.002425
5	4.1	444.9	1.651	54951.	.023	86.38	124446.7	.002457
6	8.1	519.2	1.723	53350.	.023	73.34	125056.8	.002469
7	16.4	593.1	1.725	50410.	.022	65.08	125787.1	.002483
8	24.6	653.0	1.708	47907.	.025	59.80	126040.6	.002488
9	32.5	698.3	1.675	45769.	.026	56.92	126287.1	.002493
10	40.9	745.2	1.642	43763.	.029	54.25	126315.1	.002494
11	48.9	784.6	1.608	42033.	.030	52.55	126508.3	.002497
12	57.0	829.8	1.584	40478.	.034	50.41	126455.6	.002496
13	65.0	864.6	1.551	39108.	.036	49.56	126499.2	.002497
14	73.3	893.2	1.512	37806.	.038	49.66	126498.6	.002497
15	81.5	921.8	1.478	36650.	.042	49.70	126223.4	.002492
16	90.3	928.3	1.422	35538.	.066	51.93	123450.7	.002437
17	98.3	796.6	1.246	34792.	.437	65.98	90759.6	.001792

PT	X/D	STATIC PRESS. (PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	88.7	1.19	67.6	-.512E-02
2	90.4	71.5	1.42	516.7	.280E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
46161.	30486.	.00549

RUN 93HF, DATE 10/13/75, GAS HE-AR, MOLECULAR WT. = 15.83
TIN = 72.3 F, TOUT = 348.8 F, MASS FLOW RATE = 14.1 LB/HR, I = 80.0 AMPS, E = 4.535 VOLTS
PR,IN = .418, GR/RESQ = .187E-03, MACH(2) = .107, MACH(16) = .134, T,SURR = 75.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	120.3	1.091	31673.	.067	194.11	36616.7	.001289
3	1.2	178.1	1.193	31523.	.140	83.56	34390.1	.001211
4	2.1	209.2	1.246	31401.	.054	70.53	37309.7	.001314
5	4.1	236.1	1.282	31125.	.026	61.97	38384.3	.001351
6	8.1	267.7	1.313	30607.	.024	54.12	38555.7	.001357
7	16.4	306.1	1.326	29597.	.024	48.48	38649.4	.001361
8	24.5	331.3	1.316	28687.	.025	46.71	38705.0	.001363
9	32.4	355.5	1.307	27872.	.026	45.13	38717.9	.001363
10	40.3	377.9	1.293	27067.	.028	44.32	38702.5	.001363
11	48.7	404.3	1.288	26354.	.031	42.46	38687.9	.001362
12	56.8	421.8	1.271	25679.	.032	42.73	38674.3	.001362
13	64.8	439.8	1.255	25060.	.033	42.92	38684.6	.001362
14	73.1	462.7	1.246	24451.	.037	42.11	38599.9	.001359
15	81.3	482.5	1.234	23885.	.042	41.90	38481.3	.001355
16	90.1	491.9	1.207	23323.	.073	43.63	37399.8	.001317
17	98.0	411.6	1.078	22912.	.273	97.21	31339.4	.001103

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	95.9	1.07	71.5	-.589E-02
2	90.1	92.3	1.21	328.7	.197E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
27508.	22429.	.00638

RUN 94HF, DATE 10/13/75, GAS HE-AR, MOLECULAR WT. = 15.83
TIN = 72.8 F, TOUT = 583.2 F, MASS FLOW RATE = 14.1 LB/HR, I = 118.6 AMPS, E = 7.085 VOLTS
PR,IN = .418, GR/RESQ = .407E-03, MACH(2) = .107, MACH(16) = .161, T,SURR = 73.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	199.0	1.234	31584.	.093	158.74	79013.0	.002775
3	1.2	322.9	1.449	31259.	.148	77.42	75890.4	.002667
4	2.1	390.9	1.560	31001.	.053	66.89	83189.3	.002923
5	4.1	462.6	1.652	30411.	.037	56.25	84907.8	.002984
6	8.1	544.2	1.720	29343.	.036	47.47	85470.4	.003003
7	16.4	635.2	1.721	27407.	.037	41.08	85947.1	.003020
8	24.6	705.5	1.693	25803.	.041	37.37	85991.8	.003022
9	32.5	754.9	1.644	24462.	.043	35.69	86094.4	.003025
10	40.9	833.9	1.595	23203.	.048	34.25	85989.1	.003022
11	48.9	852.3	1.556	22169.	.052	33.00	85945.7	.003020
12	57.0	892.4	1.511	21237.	.057	32.47	85817.6	.003015
13	65.0	924.8	1.464	20417.	.059	32.62	85795.5	.003014
14	73.4	969.3	1.430	19640.	.066	32.01	85537.3	.003006
15	81.5	1006.2	1.395	18924.	.074	31.88	85360.9	.002983
16	90.4	1015.7	1.335	18282.	.119	33.33	81739.7	.002872
17	98.4	831.7	1.130	17894.	.885	49.25	47896.7	.001683

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	95.8	1.18	73.2	-.589E-02
2	90.4	90.4	1.33	545.4	.300E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
24956.	17318.	.00655

RUN 98HP, DATE 10/20/75, GAS HE-AR, MOLECULAR WT. = 15.83
TIN = 73.2 F, TOUT = 570.4 F, MASS FLOW RATE = 30.8 LB/HR, I = 160.9 AMPS, E = 9.670 VOLTS
PR,IN = .418, GR/RESQ = .213E-03, MACH(2) = .204, MACH(16) = .340, T,SURR = 79.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	235.9	1.259	69554.	.058	285.58	150418.8	.002417
3	1.2	350.4	1.517	68910.	.092	135.09	147299.2	.002366
4	2.1	418.9	1.631	68401.	.029	115.83	157043.5	.002523
5	4.1	490.3	1.729	67285.	.022	97.85	158841.7	.002552
6	8.1	559.8	1.787	65254.	.020	85.50	160013.2	.002571
7	16.4	641.1	1.791	61530.	.020	75.28	160388.0	.002585
8	24.6	705.7	1.772	58370.	.022	68.94	161295.3	.002591
9	32.5	759.6	1.744	55688.	.024	64.72	161519.2	.002597
10	40.9	809.6	1.707	53172.	.026	61.55	161776.9	.002599
11	48.9	859.6	1.680	51003.	.029	58.48	161951.9	.002602
12	57.0	894.3	1.636	49083.	.030	57.53	162082.3	.002604
13	65.0	931.9	1.601	47376.	.033	56.32	162139.7	.002605
14	73.4	970.6	1.568	45758.	.035	55.27	162139.8	.002605
15	81.6	996.8	1.527	44325.	.039	55.60	161899.3	.002601
16	90.4	1002.0	1.465	42947.	.059	57.99	158784.5	.002551
17	98.4	861.7	1.282	41994.	.407	71.18	118411.6	.001902

PT	X/D	STATIC PRESS. (PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	109.4	1.20	68.2	-.488E-02
2	90.4	88.7	1.46	537.9	.275E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
56296.	36396.	.00517

RUN 97HP, DATE 10/20/75, GAS HE-AR, MOLECULAR WT. = 15.83
TIN = 72.3 F, TOUT = 298.2 F, MASS FLOW RATE = 35.3 LB/HR, I = 117.2 AMPS, E = 5.790 VOLTS
PR,IN = .418, GR/RESQ = .836E-04, MACH(2) = .238, MACH(16) = .337, T,SURR = 75.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	131.5	1.129	80349.	.049	333.86	79993.4	.001124
3	1.2	199.2	1.253	80006.	.078	156.22	78204.2	.001099
4	2.1	231.6	1.309	79735.	.024	132.51	82555.1	.001160
5	4.1	264.6	1.359	79124.	.017	112.68	83345.5	.001171
6	8.1	291.3	1.385	77995.	.013	102.45	83824.7	.001178
7	16.4	321.0	1.389	75803.	.012	95.65	84077.0	.001181
8	24.5	351.3	1.396	73808.	.013	89.06	84153.5	.001182
9	32.4	366.9	1.379	71996.	.013	88.74	84302.6	.001184
10	40.8	390.2	1.373	70209.	.014	85.66	84314.8	.001184
11	48.7	408.2	1.361	68614.	.014	84.61	84435.8	.001186
12	56.8	433.1	1.360	67089.	.016	81.05	84434.7	.001186
13	64.8	452.9	1.352	65693.	.017	79.45	84496.5	.001187
14	73.1	468.2	1.337	64312.	.017	79.78	84511.9	.001187
15	81.3	486.2	1.328	63048.	.020	78.99	84428.2	.001186
16	90.1	488.0	1.295	61787.	.031	84.33	83508.6	.001173
17	98.0	447.8	1.213	60798.	.159	105.05	74059.2	.001040

PT	X/D	STATIC PRESS. (PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	106.9	1.10	63.5	-.473E-02
2	90.1	98.5	1.29	272.3	.193E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
71091.	53547.	.00491

RUN 102H, DATE 01/28/76, GAS HE-AR, MOLECULAR WT. = 29.70
TIN = 70.1 F, TOUT = 573.9 F, MASS FLOW RATE = 36.4 LB/HR, I = 127.8 AMPS, E = 7.670 VOLTS
PR,IN = .486, GR/RESQ = .755E-03, MACH(2) = .173, MACH(16) = .258, T,SURR = 77.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	197.7	1.246	82080.	.074	403.77	93352.5	.002397
3	1.2	353.3	1.526	81302.	.157	171.51	87626.9	.002250
4	2.1	429.8	1.656	80694.	.052	149.61	96930.4	.002448
5	4.1	497.2	1.747	79314.	.034	129.60	99071.8	.002543
6	8.1	573.2	1.815	76799.	.033	111.67	99727.5	.002560
7	16.4	663.5	1.832	72178.	.034	96.47	100240.4	.002573
8	24.6	726.4	1.807	68290.	.037	88.45	100391.2	.002577
9	32.5	776.3	1.770	64994.	.040	83.42	100492.6	.002580
10	40.9	820.5	1.723	61915.	.043	79.88	100454.8	.002579
11	48.9	864.9	1.687	59322.	.046	76.59	100466.7	.002579
12	57.0	903.3	1.646	56964.	.050	74.42	100362.5	.002577
13	65.0	931.0	1.599	54893.	.052	74.06	100379.9	.002577
14	73.4	969.6	1.565	52922.	.057	72.35	100180.5	.002572
15	81.5	993.6	1.520	51185.	.062	72.78	99864.0	.002564
16	90.4	999.8	1.458	49522.	.098	74.44	96569.4	.002479
17	98.4	786.6	1.205	48437.	.568	114.98	66686.2	.001712

PT	X/D	STATIC PRESS. (PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	110.6	1.20	67.0	-.470E-02
2	90.4	97.1	1.46	541.2	.245E+01

RUN 103H, DATE 01/28/76, GAS HE-AR, MOLECULAR WT. = 29.70
TIN = 71.0 F, TOUT = 471.8 F, MASS FLOW RATE = 36.2 LB/HR, I = 113.8 AMPS, E = 6.715 VOLTS
PR,IN = .486, GR/RESQ = .593E-03, MACH(2) = .173, MACH(16) = .251, T,SURR = 90.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	191.6	1.234	81602.	.109	326.29	71673.1	.001847
3	1.2	299.7	1.428	81002.	.146	169.15	69860.6	.001800
4	2.1	354.5	1.521	80522.	.046	150.74	76889.8	.001982
5	4.1	412.7	1.604	79421.	.035	127.99	77996.3	.002010
6	8.1	462.8	1.646	77393.	.029	114.59	78785.5	.002030
7	16.4	526.0	1.655	73587.	.029	101.97	79123.1	.002039
8	24.5	574.6	1.642	70293.	.031	94.48	79231.0	.002042
9	32.4	610.7	1.614	67433.	.032	90.55	79364.3	.002045
10	40.8	649.4	1.588	64701.	.035	86.49	79300.6	.002044
11	48.8	682.5	1.561	62360.	.037	83.90	79390.5	.002045
12	56.9	715.0	1.534	60196.	.040	81.57	79301.2	.002044
13	64.9	740.6	1.502	58258.	.041	80.88	79336.5	.002045
14	73.3	767.8	1.472	56404.	.045	80.13	79237.5	.002042
15	81.5	793.0	1.443	54743.	.050	79.75	79005.6	.002036
16	90.3	799.1	1.393	53137.	.082	82.02	76660.3	.001976
17	98.2	634.9	1.175	52034.	.382	144.05	59365.5	.001530

PT	X/D	STATIC PRESS. (PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	110.0	1.19	67.4	-.471E-02
2	90.3	98.3	1.39	444.1	.212E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
67411.	45005.	.00483

RUN 104H, DATE 01/28/76, GAS HE-AR, MOLECULAR WT. = 29.70
TIN = 72.3 F, TOUT = 305.7 F, MASS FLOW RATE = 36.2 LB/HR, I = 87.4 AMPS, E = 5.020 VOLTS
PR,IN = .486, GR/RESQ = .348E-03, MACH(2) = .173, MACH(16) = .223, T,SURR = 80.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	dL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	149.3	1.153	81625.	.119	295.35	41733.4	.001072
3	1.2	209.2	1.259	81275.	.141	167.11	41120.4	.001056
4	2.1	237.5	1.309	80994.	.042	151.83	45115.3	.001159
5	4.1	264.5	1.347	80344.	.026	135.08	45939.1	.001180
6	8.1	293.8	1.377	79119.	.023	121.02	46169.8	.001186
7	16.4	329.5	1.390	76716.	.022	109.88	46304.3	.001190
8	24.5	355.5	1.387	74536.	.023	104.34	46353.7	.001191
9	32.4	374.3	1.374	72577.	.023	102.42	46423.2	.001193
10	40.8	398.9	1.368	70620.	.026	98.20	46381.5	.001192
11	48.7	421.0	1.361	68880.	.027	95.15	46416.0	.001192
12	56.8	439.4	1.348	67234.	.028	93.75	46389.1	.001192
13	64.8	455.6	1.333	65708.	.029	93.40	46417.5	.001192
14	73.1	475.9	1.323	64201.	.032	91.55	46346.5	.001191
15	81.3	492.0	1.309	62827.	.036	91.29	46244.0	.001188
16	90.1	496.1	1.278	61452.	.060	95.16	45192.9	.001161
17	98.0	414.5	1.142	60411.	.225	161.89	38861.3	.000998

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	110.1	1.12	68.0	-.471E-02
2	90.1	101.1	1.28	288.4	.162E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
71562.	53128.	.00484

RUN 105H, DATE 01/28/76, GAS HE-AR, MOLECULAR WT. = 29.70
TIN = 71.9 F, TOUT = 197.5 F, MASS FLOW RATE = 36.3 LB/HR, I = 64.9 AMPS, E = 3.585 VOLTS
PR,IN = .486, GR/RESQ = .193E-03, MACH(2) = .173, MACH(16) = .204, T,SURR = 79.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	dL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	118.1	1.096	81892.	.119	268.31	22971.3	.000590
3	1.2	147.5	1.149	81699.	.136	164.83	22663.3	.000582
4	2.1	161.3	1.173	81541.	.028	155.74	25079.0	.000644
5	4.1	177.1	1.196	81177.	.025	135.57	25186.5	.000647
6	8.1	189.7	1.208	80493.	.018	126.54	25382.8	.000652
7	16.4	207.6	1.216	79108.	.018	117.60	25418.4	.000653
8	24.5	221.9	1.218	77799.	.018	112.70	25428.0	.000653
9	32.4	233.2	1.215	76596.	.019	110.75	25442.0	.000653
10	40.7	246.7	1.215	75357.	.020	107.18	25419.6	.000653
11	48.7	257.9	1.212	74225.	.021	105.46	25432.2	.000653
12	56.8	269.2	1.209	73129.	.022	103.81	25414.1	.000653
13	64.7	278.2	1.202	72086.	.023	104.13	25421.3	.000653
14	73.1	290.3	1.200	71032.	.025	101.97	25385.4	.000652
15	81.2	298.9	1.193	70048.	.028	102.70	25328.5	.000650
16	90.0	300.7	1.175	69037.	.046	108.99	24836.6	.000639
17	97.9	262.1	1.098	68229.	.145	182.22	22686.8	.000582

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	110.5	1.08	67.2	-.471E-02
2	90.0	103.3	1.17	187.7	.130E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
75477.	61625.	.00480

RUN 107H, DATE 01/28/76, GAS HE-AR, MOLECULAR WT. = 29.70
TIN = 72.8 F, TOUT = 709.6 F, MASS FLOW RATE = 13.9 LB/HR, I = 90.0 AMPS, E = 5.370 VOLTS
PR,IN = .486, GR/RESQ = .153E-02, MACH(2) = .083, MACH(16) = .123, T,SURR = 79.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	190.6	1.216	31054.	.115	209.01	44574.7	.002976
3	1.2	326.7	1.454	30713.	.273	86.07	39412.0	.002631
4	2.1	411.0	1.594	30439.	.118	74.00	45145.0	.003014
5	4.1	498.1	1.711	29799.	.077	61.81	47167.0	.003149
6	8.1	591.6	1.792	28643.	.073	51.61	47659.6	.003182
7	16.4	694.5	1.795	26570.	.076	43.93	47860.4	.003195
8	24.6	763.8	1.753	24880.	.084	40.09	47739.3	.003187
9	32.5	816.7	1.699	23484.	.090	37.93	47630.8	.003180
10	40.9	862.4	1.636	22208.	.099	36.57	47402.5	.003165
11	48.9	903.7	1.582	21155.	.105	35.71	47285.2	.003157
12	57.0	944.7	1.533	20215.	.114	34.94	47010.1	.003139
13	65.0	978.6	1.484	19396.	.122	34.84	46812.6	.003125
14	73.4	1015.0	1.439	18621.	.131	34.74	46536.3	.003107
15	81.6	1043.2	1.394	17947.	.146	35.18	46017.5	.003072
16	90.4	1049.3	1.331	17328.	.239	35.66	42584.3	.002843
17	98.4	739.5	1.026	17003.	1.463	255.03	20977.5	.001401

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	89.1	1.18	74.0	-.591E-02
2	90.4	86.1	1.33	674.0	.297E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
24213.	16879.	.00642

RUN 108H, DATE 01/28/76, GAS HE-AR, MOLECULAR WT. = 29.70
TIN = 73.2 F, TOUT = 519.7 F, MASS FLOW RATE = 14.0 LB/HR, I = 75.1 AMPS, E = 4.320 VOLTS
PR,IN = .486, GR/RESQ = .106E-02, MACH(2) = .083, MACH(16) = .113, T,SURR = 80.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	168.6	1.177	31204.	.180	168.79	29260.3	.001945
3	1.2	254.2	1.326	30974.	.265	84.21	27464.7	.001825
4	2.1	306.1	1.413	30783.	.102	75.72	31662.7	.002105
5	4.1	360.4	1.487	30329.	.066	64.54	32856.8	.002184
6	8.1	414.5	1.534	29489.	.056	56.27	33280.0	.002212
7	16.4	490.8	1.544	27915.	.058	49.23	33380.3	.002219
8	24.5	526.7	1.524	26566.	.062	45.93	33377.5	.002218
9	32.4	566.0	1.499	25407.	.066	43.74	33345.6	.002216
10	40.8	599.5	1.464	24312.	.072	42.58	33242.9	.002210
11	48.8	635.5	1.439	23377.	.076	41.14	33176.1	.002205
12	56.9	662.7	1.405	22520.	.082	40.90	33071.3	.002198
13	64.9	690.9	1.376	21758.	.086	40.67	33003.9	.002194
14	73.3	723.3	1.352	21030.	.096	39.93	32776.7	.002179
15	81.4	745.4	1.321	20384.	.105	40.59	32558.9	.002164
16	90.2	756.7	1.279	19770.	.191	40.47	30236.4	.002010
17	98.2	551.6	1.033	19389.	.759	243.12	20186.9	.001342

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	88.9	1.14	73.6	-.590E-02
2	90.2	86.5	1.28	491.6	.239E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
25502.	18693.	.00627

RUN 109H, DATE 01/28/76, GAS HE-AR, MOLECULAR WT. = 29.70
TIN = 74.1 F, TOUT = 361.3 F, MASS FLOW RATE = 13.9 LB/HR, I = 60.0 AMPS, E = 3.300 VOLTS
PR,IN = .486, GR/RESQ = .681E-03, MACH(2) = .083, MACH(16) = .103, T,SURR = 80.7 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	139.2	1.121	31140.	.197	154.86	18371.4	.001222
3	1.2	190.3	1.211	30995.	.256	83.98	17579.7	.001159
4	2.1	220.8	1.262	30872.	.090	77.30	20293.9	.001349
5	4.1	251.8	1.305	30578.	.053	67.56	21071.6	.001401
6	8.1	286.5	1.340	30020.	.047	58.82	21225.7	.001411
7	16.4	323.3	1.346	28945.	.046	53.72	21314.3	.001417
8	24.5	350.8	1.337	27983.	.047	51.31	21324.8	.001418
9	32.4	377.3	1.329	27121.	.051	49.09	21292.0	.001416
10	40.8	397.8	1.309	26276.	.054	48.71	21263.6	.001414
11	48.7	423.0	1.300	25534.	.058	47.04	21225.5	.001411
12	56.8	442.3	1.283	24835.	.062	46.37	21170.3	.001408
13	64.8	460.3	1.265	24198.	.064	47.11	21159.7	.001407
14	73.1	481.9	1.252	23573.	.071	46.55	21051.3	.001400
15	81.3	500.6	1.237	23005.	.080	46.52	20897.9	.001390
16	90.1	504.2	1.203	22452.	.145	48.68	19730.9	.001312
17	98.0	384.0	1.028	22064.	.429	299.26	15665.4	.001042

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	89.1	1.10	73.9	-.591E-02
2	90.1	87.1	1.20	341.5	.191E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
26805.	21228.	.00612

RUN 111H, DATE 01/29/76, GAS HE-AR, MOLECULAR WT. = 29.70
TIN = 67.0 F, TOUT = 247.1 F, MASS FLOW RATE = 14.2 LB/HR, I = 48.0 AMPS, E = 2.820 VOLTS
PR,IN = .486, GR/RESQ = .446E-03, MACH(2) = .084, MACH(16) = .097, T,SURR = 72.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	101.7	1.067	32094.	.116	201.07	12579.6	.000833
3	1.2	139.0	1.134	31993.	.269	86.56	11087.9	.000734
4	2.1	160.0	1.170	31911.	.095	78.39	12874.2	.000852
5	4.1	179.7	1.199	31718.	.048	69.21	13474.3	.000892
6	8.1	201.9	1.223	31345.	.042	60.50	13576.4	.000899
7	16.4	227.2	1.234	30601.	.041	54.85	13607.2	.000901
8	24.5	245.2	1.233	29918.	.042	52.62	13609.5	.000901
9	32.4	261.4	1.229	29286.	.045	51.03	13595.0	.000900
10	40.7	276.8	1.223	28656.	.048	50.07	13565.2	.000898
11	48.7	292.1	1.218	28084.	.050	48.99	13557.2	.000897
12	56.8	307.0	1.212	27536.	.054	48.07	13514.3	.000895
13	64.7	319.3	1.203	27022.	.056	48.15	13507.5	.000894
14	73.1	334.4	1.198	26513.	.062	47.30	13449.8	.000890
15	81.2	348.1	1.191	26039.	.071	46.68	13350.4	.000884
16	90.0	352.7	1.171	25572.	.130	47.67	12651.5	.000838
17	97.9	266.0	1.027	25217.	.286	280.55	11048.9	.000731

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	89.4	1.05	66.5	-.587E-02
2	90.0	87.7	1.17	234.1	.158E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
28839.	24231.	.00593

RUN 112H, DATE 01/29/76, GAS HE-AR, MOLECULAR WT. = 29.70
TIN = 67.9 F, TOUT = 182.9 F, MASS FLOW RATE = 14.2 LB/HR, I = 38.4 AMPS, E = 2.250 VOLTS
PR,IN = .486, GR/RESQ = .284E-03, MACH(2) = .084, MACH(16) = .093, T,SURR = 72.3 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	95.6	1.054	32001.	.172	151.80	7658.6	.000507
3	1.2	116.4	1.091	31938.	.227	84.67	7331.5	.000486
4	2.1	129.6	1.114	31884.	.067	75.75	8283.5	.000549
5	4.1	142.5	1.133	31759.	.050	66.48	8530.1	.000568
6	8.1	153.9	1.144	31520.	.036	61.16	8705.5	.000577
7	16.4	170.7	1.154	31032.	.038	55.38	8702.2	.000576
8	24.5	182.5	1.155	30571.	.039	53.28	8696.6	.000576
9	32.3	192.1	1.153	30141.	.040	52.53	8693.5	.000576
10	40.7	202.5	1.151	29702.	.044	51.48	8670.0	.000574
11	48.7	211.7	1.147	29296.	.044	51.12	8670.9	.000574
12	56.8	222.9	1.148	28900.	.049	49.42	8636.6	.000572
13	64.7	230.5	1.142	28528.	.050	49.90	8633.2	.000572
14	73.0	240.0	1.139	28147.	.054	49.45	8607.2	.000570
15	81.2	249.9	1.137	27790.	.064	48.35	8536.4	.000565
16	89.9	253.5	1.125	27432.	.116	49.39	8140.6	.000539
17	97.9	200.1	1.027	27149.	.234	217.49	7332.2	.000486

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	89.3	1.04	67.1	-.587E-02
2	90.0	87.9	1.12	174.4	.140E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
29720.	25898.	.00590

RUN 116H, DATE 02/21/76, GAS HE-AR, MOLECULAR WT. = 27.53
TIN = 70.1 F, TOUT = 154.2 F, MASS FLOW RATE = 44.1 LB/HR, I = 65.2 AMPS, E = 3.760 VOLTS
PR,IN = .465, GR/RESQ = .808E-04, MACH(2) = .247, MACH(16) = .307, T,SURR = 73.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	96.0	1.069	100497.	.057	430.23	24488.4	.000481
3	1.2	128.4	1.129	100309.	.130	188.90	22966.8	.000451
4	2.1	140.6	1.151	100162.	.027	174.52	25297.7	.000497
5	4.1	152.5	1.169	99822.	.018	154.26	25530.3	.000501
6	8.1	163.5	1.181	99179.	.014	142.00	25658.4	.000504
7	16.4	178.0	1.190	97897.	.014	131.66	25688.4	.000505
8	24.5	187.6	1.190	96690.	.014	128.76	25710.6	.000505
9	32.3	197.6	1.192	95548.	.015	124.98	25705.2	.000505
10	40.7	204.5	1.187	94370.	.015	125.98	25714.7	.000505
11	48.7	214.2	1.188	93303.	.016	122.87	25714.5	.000505
12	56.8	223.7	1.188	92249.	.017	120.28	25703.5	.000505
13	64.7	230.9	1.184	91243.	.017	120.46	25707.0	.000505
14	73.0	239.5	1.183	90219.	.018	119.31	25691.2	.000505
15	81.2	246.7	1.180	89268.	.021	119.52	25642.6	.000504
16	89.9	248.5	1.157	88285.	.035	126.47	25304.6	.000497
17	97.9	215.2	1.099	87476.	.096	225.52	23824.8	.000468

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	97.1	1.06	60.0	-.450E-02
2	90.0	84.2	1.17	147.3	.131E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
94402.	78875.	.00464

RUN 117H, DATE 02/21/76, GAS HE-AR, MOLECULAR WT. = 27.53
TIN = 70.1 F, TOUT = 287.8 F, MASS FLOW RATE = 44.2 LB/HR, I = 100.7 AMPS, E = 5.750 VOLTS
PR,IN = .465, GR/RESQ = .195E-03, MACH(2) = .246, MACH(16) = .352, T,SURR = 74.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	131.7	1.136	100521.	.065	451.90	58166.6	.001140
3	1.2	202.9	1.267	100069.	.114	206.43	55920.5	.001096
4	2.1	235.7	1.324	99712.	.037	179.63	60203.2	.001190
5	4.1	262.7	1.363	98903.	.020	160.09	61333.4	.001202
6	8.1	292.1	1.393	97414.	.017	143.53	61607.4	.001208
7	16.4	331.4	1.413	94475.	.018	128.26	61761.0	.001211
8	24.5	356.1	1.409	91846.	.018	122.80	61965.7	.001213
9	32.4	379.0	1.403	89457.	.019	118.39	61922.7	.001214
10	40.8	398.6	1.389	87095.	.020	116.34	61944.0	.001214
11	48.7	422.0	1.385	85011.	.021	112.17	61992.2	.001215
12	56.8	439.1	1.371	83026.	.022	111.32	61981.4	.001215
13	64.8	454.0	1.355	81207.	.022	111.68	62031.4	.001216
14	73.1	473.8	1.346	79419.	.024	109.87	61931.5	.001215
15	81.3	490.4	1.334	77779.	.027	109.50	61885.8	.001213
16	90.1	491.8	1.300	76162.	.045	116.51	60861.7	.001193
17	98.0	415.6	1.170	74930.	.175	195.34	53799.3	.001055

PT	X/D	STATIC PRESS. (PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	97.8	1.11	60.7	-.450E-02
2	90.1	80.5	1.30	272.1	.177E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
88371.	65677.	.00453

RUN 118H, DATE 02/21/76, GAS HE-AR, MOLECULAR WT. = 27.53
TIN = 70.1 F, TOUT = 407.9 F, MASS FLOW RATE = 44.9 LB/HR, I = 123.4 AMPS, E = 7.220 VOLTS
PR,IN = .465, GR/RESQ = .354E-03, MACH(2) = .223, MACH(16) = .339, T,SURR = 78.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	179.3	1.221	101647.	.084	382.46	86114.1	.001662
3	1.2	278.0	1.400	100972.	.111	200.05	84677.9	.001634
4	2.1	327.6	1.486	100431.	.036	174.60	91095.0	.001758
5	4.1	375.2	1.554	99234.	.025	151.19	92425.8	.001784
6	8.1	420.1	1.594	97016.	.021	135.21	93059.2	.001796
7	16.4	475.3	1.605	92800.	.021	121.31	93442.4	.001804
8	24.5	519.6	1.601	89109.	.022	112.57	93605.2	.001807
9	32.4	554.4	1.584	85870.	.023	107.43	93754.0	.001810
10	40.8	585.9	1.560	82755.	.025	103.88	93771.6	.001810
11	48.8	613.6	1.535	80063.	.026	101.56	93909.9	.001813
12	56.9	643.5	1.515	77558.	.028	98.75	93879.8	.001812
13	64.9	670.2	1.494	75304.	.029	97.03	93934.8	.001813
14	73.3	694.5	1.469	73127.	.032	96.28	93886.6	.001812
15	81.4	713.5	1.441	71175.	.034	96.96	93763.3	.001810
16	90.2	721.4	1.399	69273.	.057	99.87	91823.8	.001772
17	98.2	605.4	1.227	67918.	.283	147.20	75005.9	.001448

PT	X/D	STATIC PRESS. (PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	109.6	1.18	63.0	-.448E-02
2	90.2	90.6	1.40	384.6	.209E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
85507.	57344.	.00456

RUN 119H, DATE 02/21/76, GAS HE-AR, MOLECULAR WT. = 27.53
TIN = 71.9 F, TOUT = 452.4 F, MASS FLOW RATE = 44.7 LB/HR, I = 130.8 AMPS, E = 7.720 VOLTS
PR,IN = .465, GB/RESQ = .392E-03, MACH(2) = .224, MACH(16) = .355, T,SURR = 81.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	195.0	1.247	101063.	.088	379.79	96546.3	.001862
3	1.2	310.6	1.455	100308.	.116	194.69	94871.1	.001830
4	2.1	360.7	1.540	99719.	.033	175.36	102932.5	.001985
5	4.1	411.2	1.609	98383.	.024	152.65	104166.2	.002009
6	8.1	463.2	1.655	95919.	.022	135.40	104820.5	.002021
7	16.4	531.4	1.675	91295.	.022	119.03	105273.4	.002030
8	24.5	584.8	1.671	87300.	.024	109.16	105467.6	.002034
9	32.4	624.4	1.650	83833.	.025	103.80	105644.3	.002037
10	40.8	657.5	1.616	80532.	.027	100.70	105689.0	.002038
11	48.8	690.9	1.590	77699.	.028	97.66	105821.9	.002041
12	56.9	723.9	1.565	75087.	.031	94.94	105796.1	.002040
13	64.9	752.5	1.538	72748.	.032	93.43	105865.9	.002042
14	73.3	783.7	1.514	70509.	.035	91.64	105789.9	.002040
15	81.5	807.1	1.485	68517.	.039	91.62	105602.2	.002037
16	90.3	807.6	1.429	66592.	.061	96.25	103362.8	.001993
17	98.2	675.3	1.243	65258.	.329	137.89	81768.2	.001577

PT	X/D	STATIC PRESS. (PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	109.1	1.19	64.8	-.449E-02
2	90.3	88.5	1.43	427.0	.227E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
83880.	54686.	.00460

RUN 120H, DATE 02/21/76, GAS HE-AR, MOLECULAR WT. = 27.53
TIN = 71.9 F, TOUT = 208.2 F, MASS FLOW RATE = 43.7 LB/HR, I = 80.8 AMPS, E = 4.750 VOLTS
PR,IN = .465, GB/RESQ = .121E-03, MACH(2) = .249, MACH(16) = .330, T,SURR = 80.7 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	131.0	1.132	99419.	.103	289.31	36159.9	.000713
3	1.2	165.5	1.195	99143.	.096	188.89	36484.6	.000720
4	2.1	185.4	1.230	98914.	.031	167.61	38836.4	.000766
5	4.1	204.1	1.258	98394.	.021	148.35	39274.5	.000775
6	8.1	217.9	1.269	97431.	.014	140.04	39555.2	.000780
7	16.4	242.7	1.285	95506.	.015	127.00	39501.2	.000781
8	24.5	262.5	1.292	93706.	.016	119.40	39614.7	.000781
9	32.4	272.0	1.281	92068.	.015	120.33	39678.3	.000783
10	40.7	289.6	1.283	90392.	.017	115.16	39645.0	.000782
11	48.7	302.7	1.279	88882.	.017	113.39	39631.8	.000783
12	56.8	316.8	1.276	87421.	.019	110.87	39661.3	.000782
13	64.7	327.3	1.269	86044.	.019	111.05	39684.8	.000783
14	73.1	341.5	1.266	84681.	.021	108.85	39648.9	.000782
15	81.2	352.0	1.259	83404.	.024	109.06	39585.8	.000781
16	90.0	353.9	1.237	82119.	.038	115.36	39029.6	.000770
17	97.9	316.2	1.161	81098.	.146	161.25	35272.3	.000696

PT	X/D	STATIC PRESS. (PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	95.5	1.11	61.7	-.451E-02
2	90.0	80.6	1.24	197.8	.151E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
90788.	69459.	.00464

RUN 124H, DATE 03/01/76, GAS HE-AR, MOLECULAR WT. = 15.30
TIN = 70.5 F, TOUT = 183.2 F, MASS FLOW RATE = 14.2 LB/HR, I = 52.7 AMPS, E = 3.070 VOLTS
PR,IN = .419, GR/RESQ = .682E-04, MACH(2) = .113, MACH(16) = .127, T,SURR = 74.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	91.7	1.043	32217.	.057	183.33	15990.7	.000540
3	1.2	116.6	1.088	32152.	.145	79.76	14790.6	.000500
4	2.1	128.4	1.108	32102.	.040	70.71	16309.8	.000551
5	4.1	140.0	1.125	31984.	.023	61.57	16583.2	.000560
6	8.1	151.9	1.137	31758.	.018	55.39	16676.9	.000563
7	16.4	167.3	1.145	31301.	.019	50.77	16693.4	.000564
8	24.5	179.2	1.146	30867.	.019	48.72	16594.2	.000564
9	32.3	189.2	1.145	30465.	.020	47.73	16691.6	.000564
10	40.7	199.6	1.144	30051.	.022	46.80	16676.9	.000563
11	48.7	209.6	1.143	29668.	.023	45.92	16675.6	.000563
12	56.9	219.9	1.142	29294.	.025	44.97	16658.2	.000563
13	54.7	228.9	1.139	28939.	.026	44.68	16650.8	.000562
14	73.0	239.2	1.137	28576.	.028	43.84	16625.3	.000562
15	81.2	247.8	1.134	28236.	.032	43.78	16571.5	.000560
16	89.9	251.9	1.122	27888.	.055	45.84	16219.9	.000548
17	97.9	219.0	1.056	27604.	.148	93.90	14866.6	.000502

PT	X/D	STATIC PRESS. (PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	92.7	1.03	68.8	-.585E-02
2	90.0	90.0	1.12	174.5	.140E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
30057.	26548.	.00584

RUN 125H, DATE 03/01/76, GAS HE-AR, MOLECULAR WT. = 15.30
TIN = 71.0 F, TOUT = 345.8 F, MASS FLOW RATE = 14.2 LB/HR, I = 81.5 AMPS, E = 4.305 VOLTS
PR,IN = .419, GR/RESQ = .163E-03, MACH(2) = .113, MACH(16) = .142, T,SURR = 75.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	126.4	1.106	32051.	.083	166.09	37434.2	.001267
3	1.2	182.3	1.205	31902.	.140	79.94	35721.2	.001209
4	2.1	210.8	1.253	31782.	.044	70.18	39079.5	.001323
5	4.1	239.1	1.292	31504.	.027	60.73	39823.1	.001348
6	8.1	269.3	1.320	30978.	.023	53.68	40054.8	.001356
7	15.4	307.3	1.332	29961.	.023	48.25	40154.4	.001359
8	24.5	335.2	1.327	29044.	.024	45.79	40192.7	.001360
9	32.4	358.5	1.316	28218.	.025	44.46	40223.7	.001361
10	40.8	382.3	1.305	27407.	.028	43.29	40192.0	.001360
11	48.7	405.4	1.295	26689.	.029	42.22	40217.4	.001361
12	56.8	428.4	1.285	26007.	.032	41.22	40165.1	.001359
13	64.8	448.2	1.272	25381.	.033	40.94	40176.9	.001360
14	73.1	470.7	1.261	24765.	.037	40.25	40101.7	.001357
15	81.3	491.3	1.250	24203.	.041	39.84	39978.7	.001353
16	90.1	502.1	1.225	23635.	.072	40.91	38857.9	.001315
17	98.0	421.0	1.093	23210.	.275	81.51	32487.7	.001100

PT	X/D	STATIC PRESS. (PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	92.7	1.08	69.9	-.587E-02
2	90.1	89.0	1.22	325.8	.187E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
27853.	22239.	.00589

RUN 126H, DATE 03/01/76, GAS HE-AR, MOLECULAR WT. = 15.30
TIN = 71.9 F, TOUT = 167.5 F, MASS FLOW RATE = 24.5 LB/HR, I = 68.2 AMPS, E = 3.955 VOLTS
PR,IN = .419, GR/RESQ = .273E-04, MACH(2) = .234, MACH(16) = .291, T,SURR = 76.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	103.4	1.077	56023.	.071	194.39	26468.8	.000519
3	1.2	126.6	1.119	55916.	.090	114.68	26052.6	.000509
4	2.1	138.0	1.139	55829.	.024	102.74	27754.4	.000543
5	4.1	148.1	1.153	55630.	.014	92.56	28043.2	.000548
6	8.1	159.6	1.165	55256.	.012	84.37	28128.7	.000550
7	15.4	174.6	1.174	54509.	.012	78.11	28161.5	.000551
8	24.5	186.3	1.176	53802.	.012	75.05	28172.5	.000551
9	32.3	195.9	1.175	53134.	.013	73.75	28180.6	.000551
10	40.7	205.9	1.174	52458.	.014	72.53	28176.2	.000551
11	48.7	216.1	1.174	51836.	.014	70.88	28181.5	.000551
12	56.8	226.0	1.174	51221.	.015	69.59	28173.7	.000551
13	64.7	234.6	1.171	50638.	.016	69.27	28174.0	.000551
14	73.0	244.0	1.170	50053.	.017	68.55	28150.4	.000551
15	81.2	252.6	1.167	49498.	.020	68.2[illegible]	28108.0	.000550
16	89.9	254.8	1.153	48925.	.031	72.99	27790.9	.000543
17	97.9	234.7	1.107	48460.	.106	103.78	25883.9	.000505

PT	X/D	STATIC PRESS. (PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	76.7	1.06	62.8	-.514E-02
2	90.0	66.8	1.15	159.8	.142E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
52481.	44157.	.00504

RUN 127H, DATE 03/01/76, GAS HE-AR, MOLECULAR WT. = 15.30
TIN = 73.2 F, TOUT = 510.4 F, MASS FLOW RATE = 14.1 LB/HR, I = 102.2 AMPS, E = 5.990 VOLTS
PR,IN = .419, GR/RESQ = .256E-03, MACH(2) = .112, MACH(16) = .156, T,SURR = 78.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	152.7	1.149	31735.	.074	184.51	59526.6	.002016
3	1.2	246.1	1.313	31502.	.146	80.63	56131.8	.001901
4	2.1	290.2	1.385	31316.	.046	71.05	61737.6	.002091
5	4.1	334.9	1.443	30885.	.029	61.06	62919.0	.002131
6	8.1	383.9	1.484	30094.	.027	53.20	63302.9	.002144
7	16.4	444.9	1.492	28608.	.027	46.97	63534.8	.002152
8	24.5	489.5	1.476	27325.	.029	43.95	63620.6	.002155
9	32.4	525.6	1.451	26210.	.031	42.31	63695.6	.002158
10	40.8	560.4	1.423	25151.	.034	41.16	63651.5	.002156
11	48.8	594.0	1.399	24240.	.035	40.21	63739.0	.002159
12	56.9	639.7	1.391	23383.	.041	37.65	63552.0	.002153
13	64.9	670.4	1.367	22626.	.043	37.22	63580.9	.002154
14	73.2	701.5	1.344	21905.	.047	36.90	63462.2	.002150
15	81.4	731.0	1.321	21258.	.053	36.71	63232.0	.002142
16	90.2	744.5	1.291	20629.	.090	37.92	61124.7	.002070
17	98.2	613.6	1.106	20199.	.455	73.31	45405.6	.001538

PT	X/D	STATIC PRESS. (PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	92.7	1.12	72.8	-.588E-02
2	90.2	88.1	1.28	480.4	.236E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
26198.	19810.	.00605

RUN 128H, DATE 03/01/76, GAS HE-AR, MOLECULAR WT. = 15.30
TIN = 74.1 F, TOUT = 688.6 F, MASS FLOW RATE = 14.1 LB/HR, I = 121.2 AMPS, E = 7.280 VOLTS
PR,IN = .419, GR/RESQ = .355E-03, MACH(2) = .113, MACH(16) = .171, T,SURR = 81.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	198.0	1.229	31682.	.082	165.34	83373.1	.002816
3	1.2	326.6	1.453	31357.	.145	77.77	79470.5	.002684
4	2.1	395.4	1.564	31095.	.051	67.10	87057.8	.002940
5	4.1	469.0	1.659	30496.	.036	56.17	88738.3	.002997
6	8.1	548.2	1.723	29427.	.034	47.83	89461.2	.003021
7	16.4	647.6	1.735	27484.	.036	40.68	89974.6	.003035
8	24.6	717.2	1.704	25876.	.040	37.13	89973.3	.003038
9	32.5	771.0	1.660	24527.	.043	35.15	90049.4	.003041
10	40.9	821.7	1.611	23266.	.048	33.63	89939.8	.003037
11	48.9	867.3	1.567	22229.	.051	32.63	89946.1	.003038
12	57.0	911.3	1.525	21293.	.056	31.84	89781.9	.003032
13	65.0	945.9	1.480	20470.	.060	31.78	89569.4	.003025
14	73.4	970.2	1.425	19694.	.061	32.82	89734.8	.003030
15	81.6	1026.5	1.408	18974.	.074	31.14	88954.9	.003004
16	90.4	1037.3	1.349	18330.	.117	32.38	85589.3	.002890
17	98.4	848.7	1.139	17941.	.875	46.57	50360.7	.001701

PT	X/D	STATIC PRESS. (PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	92.7	1.18	74.4	-.588E-02
2	90.4	87.0	1.35	650.4	.290E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
25029.	17357.	.00616

RUN 129H, DATE 03/01/76, GAS HE-AR, MOLECULAR WT. = 15.30
TIN = 75.4 F, TOUT = 306.3 F, MASS FLOW RATE = 24.4 LB/HR, I = 102.4 AMPS, E = 5.925 VOLTS
PR,IN = .419, GR/RESQ = .609E-04, MACH(2) = .233, MACH(16) = .335, T,SURR = 82.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	145.2	1.148	55262.	.079	204.06	59450.1	.001162
3	1.2	202.0	1.249	55020.	.096	113.76	58758.9	.001149
4	2.1	229.0	1.295	54830.	.026	101.31	62852.8	.001229
5	4.1	256.0	1.333	54396.	.018	88.79	63512.7	.001242
6	8.1	284.9	1.361	53582.	.015	79.42	63791.5	.001247
7	16.4	321.9	1.376	51992.	.015	71.72	63959.8	.001251
8	24.5	349.3	1.375	50553.	.016	67.93	64045.7	.001252
9	32.4	371.8	1.367	49261.	.017	65.87	64119.4	.001254
10	40.8	394.6	1.358	47980.	.018	64.05	64126.6	.001254
11	48.7	416.7	1.350	46841.	.019	62.36	64191.1	.001255
12	56.8	437.9	1.342	45765.	.020	61.05	64179.8	.001255
13	64.8	456.3	1.331	44774.	.021	60.53	64223.2	.001256
14	73.1	476.6	1.321	43796.	.023	59.71	64189.6	.001255
15	81.3	495.4	1.311	42906.	.026	59.21	64093.8	.001253
16	90.1	500.3	1.281	42019.	.042	62.50	63112.5	.001234
17	98.0	447.0	1.183	41340.	.194	86.43	54878.2	.001073

PT	X/D	STATIC PRESS. (PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	76.7	1.12	67.0	-.515E-02
2	90.1	63.3	1.28	289.7	.194E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
48657.	36411.	.00516

RUN 130H, DATE 03/01/76, GAS HE-AR, MOLECULAR WT. = 15.30
TIN = 76.3 F, TOUT = 453.5 F, MASS FLOW RATE = 24.3 LB/HR, I = 126.0 AMPS, E = 7.440 VOLTS
PR,IN = .419, GR/RESQ = .143E-03, MACH(2) = .186, MACH(16) = .272, T,SURR = 84.7 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	176.9	1.196	54594.	.074	218.59	90625.1	.001775
3	1.2	269.7	1.360	54232.	.100	113.25	89109.7	.001747
4	2.1	312.8	1.432	53942.	.030	99.83	95469.5	.001871
5	4.1	355.8	1.489	53283.	.020	86.74	96646.6	.001894
6	8.1	402.4	1.530	52069.	.018	76.53	97152.0	.001904
7	16.4	461.6	1.545	49774.	.019	67.78	97526.1	.001912
8	24.5	504.2	1.534	47770.	.020	63.44	97719.8	.001915
9	32.4	539.1	1.514	46013.	.021	60.84	97882.8	.001919
10	40.8	573.9	1.491	44322.	.023	58.65	97915.0	.001919
11	48.8	607.3	1.472	42858.	.024	56.74	98040.9	.001922
12	56.9	637.7	1.450	41496.	.026	55.49	98031.8	.001921
13	64.9	662.7	1.424	40251.	.027	55.18	98127.4	.001923
14	73.2	693.9	1.405	39056.	.030	54.06	98054.9	.001922
15	81.4	717.8	1.381	37995.	.033	54.19	97928.3	.001919
16	90.2	726.5	1.338	36954.	.053	56.62	96081.4	.001883
17	98.2	635.8	1.199	36201.	.299	77.10	77413.0	.001517

PT	X/D	STATIC PRESS. (PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	96.3	1.15	71.9	-.516E-02
2	90.2	84.1	1.34	426.8	.222E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
45799.	32455.	.00524

RUN 131H, DATE 03/01/76, GAS HE-AR, MOLECULAR WT. = 15.30
TIN = 76.8 F, TOUT = 623.6 F, MASS FLOW RATE = 24.2 LB/HR, I = 151.1 AMPS, E = 9.100 VOLTS
PR,IN = .419, GR/RESQ = .206E-03, MACH(2) = .186, MACH(16) = .305, T,SURR = 87.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	216.8	1.268	54345.	.067	228.80	131587.2	.002582
3	1.2	354.1	1.509	53822.	.101	113.99	129787.5	.002527
4	2.1	421.2	1.618	53404.	.033	98.69	138017.9	.002709
5	4.1	489.8	1.707	52465.	.024	84.12	139860.7	.002745
6	8.1	563.7	1.767	50784.	.022	72.77	140826.2	.002764
7	16.4	658.6	1.783	47695.	.024	62.50	141568.6	.002778
8	24.6	725.6	1.758	45111.	.026	57.26	141910.8	.002785
9	32.5	779.4	1.722	42927.	.028	54.00	142163.9	.002790
10	40.9	829.3	1.678	40888.	.031	51.60	142237.3	.002791
11	48.9	875.3	1.640	39149.	.033	49.69	142391.6	.002794
12	57.0	917.6	1.601	37603.	.036	48.40	142387.7	.002794
13	65.0	950.2	1.556	36241.	.038	48.16	142450.1	.002795
14	73.4	988.4	1.519	34946.	.041	47.63	142406.5	.002795
15	81.6	1021.4	1.482	33801.	.045	47.56	142363.1	.002793
16	90.4	1029.2	1.421	32649.	.070	49.63	138833.6	.002725
17	98.4	881.1	1.237	31940.	.504	61.94	97824.7	.001920

PT	X/D	STATIC PRESS. (PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	96.3	1.21	73.1	-.517E-02
2	90.4	80.9	1.42	588.0	.280E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
43534.	28483.	.00526

RUN 133H, DATE 03/10/76, GAS HE, MOLECULAR WT. = 4.0026
TIN = 78.1 F, TOUT = 174.6 F, MASS FLOW RATE = 11.6 LB/HR, I = 87.1 AMPS, E = 4.925 VOLTS
PR,IN = .667, GR/RESQ = .112E-04, MACH(2) = .162, MACH(16) = .188, T,SURR = 75.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	99.5	1.048	30117.	.040	240.47	44446.3	.000476
3	1.2	131.5	1.105	30065.	.072	95.70	43227.7	.000463
4	2.1	142.2	1.124	30026.	.014	85.14	45754.2	.000490
5	4.1	152.4	1.138	29935.	.010	75.59	45964.4	.000493
6	8.1	162.5	1.148	29765.	.008	69.48	46085.2	.000494
7	16.4	175.7	1.154	29425.	.008	64.99	46138.3	.000494
8	24.5	185.3	1.154	29100.	.008	63.51	46169.3	.000495
9	32.3	194.0	1.153	28791.	.008	62.57	46185.4	.000495
10	40.7	201.8	1.149	28476.	.008	62.70	46198.7	.000495
11	48.7	211.1	1.149	28184.	.009	61.46	46215.1	.000495
12	56.8	220.1	1.148	27894.	.009	60.51	46219.4	.000495
13	64.7	227.3	1.144	27616.	.009	60.84	46233.4	.000495
14	73.0	236.3	1.143	27337.	.010	60.09	46227.2	.000495
15	81.2	242.6	1.137	27070.	.011	61.22	46195.3	.000495
16	89.9	244.9	1.125	26791.	.018	66.07	45902.2	.000492
17	97.9	230.6	1.088	26556.	.064	91.05	43854.7	.000470

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	103.1	1.04	73.9	-.596E-02
2	90.0	96.3	1.12	166.8	.151E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
28457.	25098.	.00622

RUN 134H, DATE 03/10/76, GAS HE, MOLECULAR WT. = 4.0026
TIN = 77.7 F, TOUT = 32[illegible].1 F, MASS FLOW RATE = 11.6 LB/HR, I = 135.4 AMPS, E = 7.890 VOLTS
PR,IN = .667, GR/RESQ = .272E-04, MACH(2) = .162, MACH(16) = .211, T,SURR = 78.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	142.6	1.129	30140.	.051	192.97	106721.3	.001143
3	1.2	211.5	1.250	30016.	.063	93.96	106024.3	.001135
4	2.1	238.1	1.295	29919.	.016	82.75	111182.7	.001190
5	4.1	263.0	1.328	29705.	.011	73.42	111915.1	.001198
6	8.1	289.3	1.351	29305.	.009	66.58	112277.2	.001202
7	16.4	322.8	1.360	28516.	.009	61.08	112565.3	.001205
8	24.5	346.7	1.354	27799.	.009	58.80	112741.7	.001207
9	32.4	366.9	1.343	27148.	.010	57.56	112881.9	.001208
10	40.8	386.1	1.328	26497.	.010	56.92	112966.1	.001209
11	48.7	407.8	1.321	25914.	.011	55.47	113097.4	.001211
12	56.8	427.7	1.310	25358.	.012	54.63	113157.9	.001211
13	64.8	444.8	1.297	24841.	.012	54.52	113264.0	.001213
14	73.1	464.7	1.287	24327.	.013	53.92	113295.2	.001213
15	81.3	481.8	1.274	23854.	.015	53.99	113261.7	.001213
16	90.1	483.6	1.240	23340.	.023	58.76	112379.0	.001203
17	98.0	452.4	1.169	22896.	.119	74.49	102462.4	.001097

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	103.3	1.10	74.1	-.596E-02
2	90.1	94.2	1.24	301.4	.199E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
26749.	20976.	.00634

RUN 135H, DATE 03/10/76, GAS = HE, MOLECULAR WT. = 4.0026
TIN = 77.7 F, TOUT = 471.7 F, MASS FLOW RATE = 11.6 LB/HR, I = 171.2 AMPS, E = 10.170 VOLTS
PR,IN = .667, GR/RESQ = .435E-04, MACH(2) = .163, MACH(16) = .235, T,SURR = 82.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	190.3	1.215	30091.	.055	178.22	170678.3	.001827
3	1.2	294.1	1.398	29894.	.061	93.56	170966.9	.001830
4	2.1	338.5	1.471	29741.	.017	81.58	178844.3	.001915
5	4.1	379.5	1.523	29402.	.012	72.05	180275.8	.001930
6	8.1	423.6	1.557	28772.	.011	64.59	181028.5	.001938
7	16.4	479.8	1.563	27580.	.011	58.17	181743.6	.001946
8	24.5	520.2	1.545	26536.	.012	55.06	182172.1	.001950
9	32.4	552.4	1.518	25616.	.012	53.40	182524.9	.001954
10	40.8	583.9	1.489	24725.	.013	52.20	182743.1	.001956
11	48.8	616.6	1.467	23949.	.013	50.81	183058.2	.001960
12	56.9	648.0	1.445	23168.	.015	49.64	183221.5	.001962
13	64.9	673.7	1.418	22484.	.015	49.42	183458.5	.001964
14	73.3	703.2	1.396	21861.	.017	48.97	183569.7	.001965
15	81.4	728.4	1.371	21295.	.019	49.15	183551.8	.001965
16	90.2	731.5	1.321	20735.	.028	53.24	181637.3	.001947
17	98.2	680.5	1.224	20303.	.183	64.29	157493.5	.001686

PT	X/D	STATIC PRESS. (PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	103.1	1.16	74.7	-.596E-02
2	90.3	91.6	1.32	442.3	.253E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
25428.	18139.	.00652

RUN 136H, DATE 03/10/76, GAS = HE, MOLECULAR WT. = 4.0026
TIN = 76.8 F, TOUT = 618.7 F, MASS FLOW RATE = 11.6 LB/HR, I = 199.6 AMPS, E = 12.015 VOLTS
PR,IN = .667, GR/RESQ = .598E-04, MACH(2) = .162, MACH(16) = .258, T,SURR = 86.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	230.2	1.289	30055.	.050	179.54	233859.2	.002510
3	1.2	369.2	1.533	29786.	.060	94.72	233974.0	.002511
4	2.1	434.9	1.640	29578.	.019	81.07	244549.5	.002625
5	4.1	493.7	1.711	29117.	.013	70.94	246839.2	.002649
6	8.1	559.9	1.760	28281.	.013	62.43	248133.9	.002663
7	16.4	642.3	1.760	26735.	.013	55.00	249459.0	.002677
8	24.6	699.2	1.725	25427.	.014	51.41	250214.1	.002686
9	32.5	744.9	1.682	24303.	.015	49.27	250806.7	.002692
10	40.9	787.2	1.633	23201.	.016	47.77	251208.9	.002696
11	48.9	829.0	1.594	22265.	.017	46.40	251684.4	.002701
12	57.0	867.2	1.554	21460.	.018	45.68	251989.9	.002705
13	65.0	899.8	1.513	20737.	.019	45.58	252310.2	.002708
14	73.4	938.4	1.479	20042.	.021	45.15	252560.5	.002711
15	81.6	972.9	1.446	19419.	.024	45.11	252496.9	.002710
16	90.4	977.2	1.382	18813.	.035	48.57	249770.0	.002681
17	98.4	897.4	1.258	18368.	.260	57.04	204094.9	.002191

PT	X/D	STATIC PRESS. (PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	103.2	1.22	74.5	-.596E-02
2	90.4	89.2	1.38	579.9	.309E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
24454.	16195.	.00669

RUN 1494, DATE 04/02/76, GAS AIR , MOLECULAR WT. = 28.97
TIN = 74.5 F, TOUT = 153.5 F, MASS FLOW RATE = 35.6 LB/HR, I = 64.2 AMPS, E = 3.555 VOLTS
PR.IN = .720, GR/RESQ = .162E-03, MACH(2) = .225, MACH(16) = .250, T,SURR = 76.7 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	103.8	1.064	100225.	.074	550.66	23386.1	.000417
3	1.2	137.5	1.126	100058.	.145	244.03	21993.2	.000392
4	2.1	149.9	1.148	99947.	.031	229.05	24454.6	.000436
5	4.1	160.9	1.164	99667.	.019	204.87	24745.1	.000441
6	8.1	171.5	1.176	99137.	.015	189.03	24662.9	.000443
7	16.4	185.0	1.185	98056.	.015	175.74	24899.5	.000444
8	24.5	195.5	1.188	97025.	.015	163.74	24911.1	.000444
9	32.4	203.3	1.186	96050.	.015	158.21	24922.1	.000445
10	40.7	211.6	1.185	95072.	.016	153.54	24917.4	.000444
11	48.7	220.2	1.185	94161.	.016	160.06	24923.1	.000445
12	56.8	223.3	1.184	93254.	.017	157.48	24915.6	.000444
13	64.7	235.0	1.180	92392.	.018	155.94	24915.8	.000444
14	73.0	242.7	1.178	91485.	.019	155.42	24904.3	.000444
15	81.2	249.9	1.176	90529.	.022	154.10	24847.9	.000443
16	89.9	248.5	1.158	89740.	.035	166.39	24527.5	.000437
17	97.9	212.1	1.086	89002.	.092	304.19	23179.2	.000423

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	92.1	1.05	69.6	-.450E-02
2	90.0	84.4	1.16	151.7	.117E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
94992.	80621.	.00451

RUN 1504, DATE 04/02/76, GAS AIR , MOLECULAR WT. = 29.97
TIN = 75.9 F, TOUT = 236.5 F, MASS FLOW RATE = 35.4 LB/HR, I = 69.1 AMPS, E = 5.720 VOLTS
PR.IN = .720, GR/RESQ = .386E-03, MACH(2) = .224, MACH(16) = .293, T,SURR = 79.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	151.5	1.150	99494.	.092	504.00	55011.5	.000963
3	1.2	230.2	1.293	99120.	.137	240.35	53151.4	.000950
4	2.1	265.3	1.354	98827.	.041	215.14	58175.8	.001039
5	4.1	295.0	1.397	98164.	.025	191.52	59249.8	.001058
6	8.1	322.4	1.425	96918.	.021	174.64	59609.6	.001065
7	16.4	355.4	1.437	94489.	.020	163.24	59797.0	.001068
8	24.5	379.2	1.433	92278.	.020	152.72	59685.4	.001070
9	32.4	398.8	1.424	90227.	.020	148.02	59959.7	.001071
10	40.6	413.1	1.414	88145.	.022	143.35	59952.2	.001071
11	48.7	437.5	1.403	86299.	.022	140.05	60020.9	.001072
12	56.8	456.0	1.393	84540.	.024	136.95	59995.6	.001072
13	64.8	470.9	1.379	82926.	.024	135.99	60037.7	.001073
14	73.2	485.6	1.365	81338.	.026	134.64	60004.9	.001072
15	81.3	502.5	1.353	79850.	.029	133.03	59893.3	.001070
16	90.1	501.8	1.317	78341.	.047	139.46	58821.6	.001051
17	98.0	408.5	1.163	77201.	.166	244.07	52513.7	.000938

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	92.1	1.12	71.5	-.451E-02
2	90.1	82.0	1.32	270.7	.155E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
88742.	65447.	.00452

RUN 1514, DATE 04/02/76, GAS AIR , MOLECULAR WT. = 28.97
TIN = 77.2 F, TOUT = 404.9 F, MASS FLOW RATE = 35.3 LB/HR, I = 122.7 AMPS, E = 7.290 VOLTS
PR,IN = .720, GR/RESQ = .589E-03, MACH(2) = .224, MACH(16) = .324, T,SURR = 83.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	197.9	1.233	99836.	.100	482.05	83998.6	.001502
3	1.2	320.3	1.453	99264.	.141	233.60	81761.5	.001402
4	2.1	373.6	1.544	97616.	.041	211.39	89938.5	.001608
5	4.1	422.1	1.613	96803.	.029	185.75	91235.6	.001633
6	8.1	469.2	1.655	94937.	.025	166.63	91976.3	.001645
7	16.4	523.7	1.669	91413.	.024	149.46	92374.0	.001652
8	24.5	564.4	1.659	89214.	.025	139.39	92544.2	.001655
9	32.4	595.6	1.639	85332.	.026	133.24	92701.3	.001658
10	40.8	630.5	1.619	82659.	.029	127.31	92684.7	.001658
11	48.8	658.6	1.595	80314.	.029	123.50	92919.4	.001660
12	56.9	687.7	1.574	78068.	.032	119.03	92766.7	.001659
13	64.9	709.4	1.546	75601.	.032	117.36	92648.7	.001660
14	73.3	735.4	1.523	74101.	.035	114.94	92762.2	.001659
15	81.5	754.0	1.495	72304.	.038	114.60	92603.9	.001656
16	90.2	752.8	1.441	70598.	.062	119.65	90513.9	.001619
17	98.2	597.9	1.223	69364.	.266	194.04	75101.4	.001343

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	91.9	1.18	73.3	-.451E-02
2	90.3	79.3	1.44	381.6	.194E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
84755.	55947.	.00462

RUN 1524, DATE 04/02/76, GAS AIR , MOLECULAR WT. = 28.97
TIN = 77.7 F, TOUT = 527.6 F, MASS FLOW RATE = 35.2 LB/HR, I = 143.2 AMPS, E = 8.635 VOLTS
PR,IN = .719, GR/RESQ = .806E-03, MACH(2) = .223, MACH(16) = .354, T,SURR = 87.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	247.4	1.322	98212.	.098	469.44	115141.7	.002066
3	1.2	410.8	1.514	97433.	.141	233.27	112076.7	.002011
4	2.1	489.3	1.747	96817.	.044	207.59	123202.4	.002211
5	4.1	559.5	1.843	95442.	.033	180.55	125160.4	.002246
6	8.1	629.4	1.902	92990.	.029	159.56	126173.9	.002264
7	16.5	709.2	1.911	88346.	.029	140.11	126843.2	.002276
8	24.6	766.5	1.885	84330.	.032	129.16	127081.4	.002281
9	32.5	811.7	1.848	80933.	.033	122.25	127274.2	.002284
10	40.9	856.1	1.807	77683.	.036	115.67	127275.5	.002284
11	48.9	895.9	1.770	74936.	.038	110.80	127383.2	.002286
12	57.0	932.7	1.732	72383.	.041	107.38	127344.9	.002285
13	65.0	961.0	1.689	70157.	.043	105.41	127369.6	.002286
14	73.4	994.1	1.652	67995.	.046	102.79	127290.3	.002284
15	81.6	1015.1	1.607	66031.	.050	102.80	126958.7	.002279
16	90.4	1009.6	1.535	64208.	.077	105.95	123773.8	.002221
17	98.4	790.8	1.266	62993.	.405	159.49	93440.9	.001677

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	91.8	1.25	74.3	-.452E-02
2	90.4	76.7	1.53	497.7	.234E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
81264.	48907.	.00453

RUN 154H, DATE 04/02/76, GAS AIR , MOLECULAR WT. = 28.97
TIN = 77.7 F, TOUT = 171.2 F, MASS FLOW RATE = 29.0 LB/HR, I = 59.5 AMPS, E = 3.260 VOLTS
PR.IN = .719, GR/RESQ = .239E-03, MACH(2) = .170, MACH(16) = .188, T.SURR = 32.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	109.1	1.063	81164.	.083	441.12	20129.3	.000437
3	1.2	141.8	1.123	81031.	.105	233.32	13753.6	.000405
4	2.1	154.7	1.145	80928.	.037	191.53	21098.0	.000459
5	4.1	166.1	1.162	80686.	.022	172.24	21415.7	.000465
6	8.1	177.6	1.174	80227.	.018	158.08	21523.5	.000468
7	16.4	190.6	1.181	79293.	.017	143.59	21564.5	.000469
8	24.5	201.1	1.182	78407.	.017	143.31	21572.3	.000469
9	32.4	208.9	1.180	77595.	.017	141.75	21564.6	.000469
10	40.7	218.7	1.180	75750.	.019	137.64	21569.2	.000469
11	48.7	227.3	1.179	75963.	.019	135.48	21576.9	.000469
12	56.8	235.8	1.177	75181.	.020	133.22	21565.5	.000469
13	64.7	243.0	1.174	74425.	.021	132.66	21555.2	.000469
14	73.0	251.6	1.172	73655.	.022	130.72	21546.3	.000468
15	81.2	253.8	1.168	72918.	.026	130.10	21492.7	.000467
16	89.9	259.3	1.153	72152.	.042	137.91	21146.7	.000460
17	97.9	220.1	1.077	71526.	.109	261.59	19818.5	.000431

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	99.9	1.05	75.0	-.472E-02
2	90.0	95.2	1.15	163.8	.115E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
76666.	65365.	.00469

RUN 155H, DATE 04/02/76, GAS AIR , MOLECULAR WT. = 28.97
TIN = 78.6 F, TOUT = 298.5 F, MASS FLOW RATE = 29.1 LB/HR, I = 90.6 AMPS, E = 5.220 VOLTS
PR.IN = .719, GR/RESQ = .544E-03, MACH(2) = .170, MACH(16) = .212, T.SURR = 33.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	151.4	1.139	81065.	.099	432.69	45674.3	.000990
3	1.2	225.4	1.274	80761.	.156	204.97	43058.3	.000946
4	2.1	262.4	1.336	80519.	.051	182.46	48171.9	.001044
5	4.1	293.0	1.381	79970.	.029	161.92	49300.8	.001068
6	8.1	321.3	1.409	78934.	.024	146.98	49643.6	.001076
7	16.4	354.2	1.420	76941.	.023	134.84	49809.0	.001079
8	24.5	378.0	1.416	75103.	.023	129.55	49878.1	.001081
9	32.4	397.1	1.405	73397.	.023	124.29	49941.7	.001082
10	40.6	413.3	1.396	71665.	.025	120.56	49916.5	.001082
11	48.7	437.7	1.386	70159.	.026	117.58	49969.3	.001083
12	56.8	457.1	1.376	68696.	.028	114.58	49926.3	.001082
13	64.8	471.0	1.360	67383.	.028	114.33	49972.1	.001083
14	73.2	489.4	1.349	66059.	.031	112.09	49903.7	.001081
15	81.3	503.2	1.334	64820.	.034	111.60	49810.9	.001079
16	90.1	506.0	1.302	63575.	.058	114.93	48858.9	.001055
17	98.0	405.0	1.140	62655.	.169	216.64	43005.3	.000932

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	99.9	1.11	76.4	-.472E-02
2	90.1	93.7	1.30	262.0	.151E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
72340.	54080.	.00475

RUN 1564, DATE 04/02/76, GAS AIR , MOLECULAR WT. = 28.97
TIN = 79.0 F, TOUT = 423.3 F, MASS FLOW RATE = 29.0 LB/HR, I = 112.9 AMPS, E = 6.665 VOLTS
PR,IN = .719, GR/RESQ = .842E-03, MACH(2) = .170, MACH(16) = .231, T,SURR = 85.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	195.2	1.213	80768.	.108	413.54	70496.4	.001529
3	1.2	312.7	1.429	80297.	.161	200.83	67435.3	.001471
4	2.1	368.3	1.522	79823.	.050	130.37	75253.7	.001633
5	4.1	417.3	1.591	79074.	.033	158.84	76617.0	.001665
6	8.1	464.2	1.634	77528.	.029	141.86	77402.1	.001679
7	16.4	519.3	1.645	74557.	.028	127.21	77745.6	.001686
8	24.5	559.1	1.632	71682.	.029	118.89	77876.0	.001689
9	32.4	590.1	1.608	69534.	.030	114.18	75602.9	.001692
10	40.8	622.6	1.585	67231.	.033	109.49	77960.6	.001691
11	48.8	650.8	1.561	65313.	.033	106.14	78061.5	.001693
12	56.9	679.1	1.533	63438.	.036	102.56	77989.4	.001692
13	64.9	700.7	1.509	61730.	.037	101.40	78046.2	.001693
14	73.3	725.9	1.484	60134.	.040	99.62	77945.7	.001691
15	81.4	745.4	1.456	58667.	.044	99.44	77769.6	.001687
16	90.2	745.9	1.404	57233.	.073	102.38	75692.3	.001642
17	98.2	583.3	1.181	56201.	.296	183.10	61953.0	.001344

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	99.7	1.17	77.3	-.472E-02
2	90.3	92.1	1.40	398.3	.146E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
69032.	46754.	.00479

RUN 1574, DATE 04/02/76, GAS AIR , MOLECULAR WT. = 28.97
TIN = 79.5 F, TOUT = 555.5 F, MASS FLOW RATE = 28.9 LB/HR, I = 132.2 AMPS, E = 7.960 VOLTS
PR,IN = .719, GR/RESQ = .116E-02, MACH(2) = .170, MACH(16) = .253, T,SURR = 88.7 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	243.2	1.305	80324.	.109	408.61	97116.6	.002112
3	1.2	401.4	1.584	79677.	.161	200.90	93758.5	.002039
4	2.1	479.5	1.715	79162.	.051	179.67	104179.0	.002266
5	4.1	549.2	1.809	79001.	.037	156.22	105092.6	.002308
6	8.1	616.5	1.863	75953.	.033	136.27	107025.2	.002328
7	16.4	694.8	1.865	72030.	.033	121.73	107583.7	.002340
8	24.6	749.5	1.834	68674.	.036	112.82	107761.3	.002344
9	32.5	792.4	1.792	65646.	.037	107.22	107908.5	.002347
10	40.9	834.9	1.748	63119.	.041	101.69	107864.1	.002346
11	48.9	873.1	1.708	60837.	.043	97.97	107938.7	.002348
12	57.0	903.6	1.667	58718.	.046	95.21	107852.5	.002346
13	65.0	933.3	1.619	56859.	.047	94.25	107667.3	.002347
14	73.4	965.1	1.581	55036.	.051	92.52	107779.1	.002344
15	81.6	992.1	1.543	53430.	.056	91.46	107419.6	.002336
16	90.4	993.9	1.479	51898.	.088	93.42	104245.4	.002267
17	98.4	766.1	1.207	50863.	.445	155.92	77331.6	.001652

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	99.6	1.24	78.3	-.472E-02
2	90.4	90.6	1.48	523.5	.223E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
66150.	41168.	.00479

RUN 159H, DATE 04/08/76, GAS AIR , MOLECULAR WT. = 28.97
TIN = 73.7 F, TOUT = 175.5 F, MASS FLOW RATE = 20.1 LB/HR, I = 52.2 AMPS, E = 2.830 VOLTS
PR.IN = .720, GR/RESQ = .214E-03, MACH(2) = .157, MACH(16) = .174, T.SURR = 76.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	103.6	1.060	56552.	.104	344.49	15033.3	.000475
3	1.2	135.9	1.119	56454.	.209	153.02	13769.7	.000435
4	2.1	151.6	1.146	56375.	.059	142.42	15737.2	.000497
5	4.1	165.6	1.163	56192.	.034	125.79	16132.0	.000509
6	8.1	177.5	1.181	55841.	.025	110.12	16236.2	.000514
7	16.4	192.3	1.188	55128.	.024	105.12	16315.9	.000515
8	24.5	203.2	1.189	54448.	.025	104.58	16325.7	.000516
9	32.4	212.8	1.188	53830.	.025	102.22	16325.1	.000516
10	40.7	222.2	1.186	53189.	.027	100.45	16314.1	.000515
11	48.7	232.1	1.185	52593.	.028	97.94	16309.9	.000515
12	56.8	240.2	1.181	52002.	.029	97.37	16303.0	.000515
13	64.7	248.8	1.179	51435.	.030	96.20	16291.2	.000515
14	73.1	257.3	1.175	50853.	.032	95.35	16273.4	.000514
15	81.2	265.9	1.172	50299.	.037	94.06	16207.2	.000512
16	89.9	266.8	1.157	49729.	.063	98.64	15803.2	.000499
17	97.9	215.0	1.060	49284.	.139	247.11	14695.1	.000464

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	74.5	1.05	71.5	-.513E-02
2	90.0	71.2	1.15	168.5	.125E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
53146.	45344.	.00508

RUN 160H, DATE 04/08/76, GAS AIR , MOLECULAR WT. = 28.97
TIN = 74.5 F, TOUT = 316.2 F, MASS FLOW RATE = 20.1 LB/HR, I = 79.2 AMPS, E = 4.495 VOLTS
PR.IN = .720, GR/RESQ = .491E-03, MACH(2) = .157, MACH(16) = .198, T.SURR = 78.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	144.6	1.134	56288.	.119	340.41	34269.2	.001083
3	1.2	219.3	1.268	56063.	.205	154.56	31995.6	.001011
4	2.1	258.1	1.336	55882.	.071	138.02	36103.6	.001141
5	4.1	292.2	1.386	55464.	.040	121.46	37254.7	.001177
6	8.1	322.8	1.416	54673.	.033	109.86	37620.2	.001189
7	15.4	358.9	1.428	53151.	.032	100.05	37752.9	.001193
8	24.5	384.5	1.422	51758.	.032	95.15	37800.4	.001194
9	32.4	404.9	1.409	50471.	.033	92.39	37844.7	.001196
10	40.8	426.1	1.395	49195.	.035	89.68	37804.3	.001194
11	48.7	446.3	1.384	48060.	.036	87.58	37839.0	.001196
12	56.9	466.6	1.372	46993.	.039	85.44	37776.1	.001194
13	64.8	482.8	1.356	46018.	.040	84.90	37800.6	.001194
14	73.2	503.3	1.345	45038.	.044	82.74	37702.9	.001191
15	81.3	517.6	1.327	44126.	.048	82.60	37598.7	.001188
16	90.1	521.6	1.294	43251.	.084	84.31	36348.3	.001148
17	98.0	400.0	1.108	42597.	.250	137.80	31255.0	.000988

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	74.5	1.11	72.9	-.513E-02
2	90.1	70.2	1.29	298.5	.164E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
49783.	37493.	.00513

RUN 1614, DATE 04/08/76, GAS AIR , MOLECULAR WT. = 28.97
TIN = 75.4 F, TOUT = 445.3 F, MASS FLOW RATE = 20.0 LB/HR, I = 97.6 AMPS, E = 5.725 VOLTS
PR.IN = .720, GR/RESQ = .753E-03, MACH(2) = .156, MACH(16) = .214, T.SURR = 30.3 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	183.5	1.213	55890.	.138	315.26	51343.0	.001627
3	1.2	299.0	1.410	55550.	.206	152.23	48344.3	.001548
4	2.1	357.8	1.510	55276.	.071	135.32	55245.4	.001751
5	4.1	411.4	1.586	54645.	.046	113.72	56759.8	.001799
6	8.1	460.1	1.630	53489.	.039	106.10	57367.6	.001819
7	16.4	513.4	1.540	51290.	.038	94.52	57619.6	.001825
8	24.5	559.0	1.622	49308.	.040	88.34	57698.0	.001829
9	32.4	591.3	1.596	47595.	.041	84.62	57774.4	.001831
10	40.6	624.7	1.569	45964.	.045	81.35	57668.5	.001828
11	48.8	655.4	1.545	44531.	.046	78.44	57731.9	.001830
12	56.9	685.0	1.520	43198.	.051	75.85	57610.9	.001826
13	64.9	705.2	1.488	42002.	.052	75.46	57651.4	.001827
14	73.3	733.9	1.463	40828.	.057	73.99	57468.4	.001822
15	81.4	753.8	1.433	39798.	.062	73.76	57279.7	.001815
16	90.2	753.5	1.380	38778.	.103	75.79	55121.4	.001747
17	98.2	567.0	1.134	38070.	.392	165.80	43121.0	.001367

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	74.7	1.17	74.3	-.514E-02
2	90.3	69.5	1.33	419.8	.203E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
47355.	32532.	.00526

RUN 1624, DATE 04/08/76, GAS AIR , MOLECULAR WT. = 28.97
TIN = 76.8 F, TOUT = 586.5 F, MASS FLOW RATE = 20.0 LB/HR, I = 114.8 AMPS, E = 6.890 VOLTS
PR.IN = .719, GR/RESQ = .103E-02, MACH(2) = .157, MACH(16) = .234, T.SURR = 34.7 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	236.8	1.298	55787.	.138	308.36	71310.5	.002251
3	1.2	383.5	1.566	55319.	.208	151.00	67684.9	.002143
4	2.1	470.7	1.704	54940.	.072	135.46	76985.6	.002430
5	4.1	549.7	1.813	54073.	.052	115.80	78853.2	.002489
6	8.1	624.9	1.876	52541.	.046	101.25	79743.6	.002517
7	16.4	710.4	1.879	49627.	.047	89.12	80165.1	.002531
8	24.6	770.3	1.845	47167.	.050	81.14	80210.0	.002532
9	32.5	815.8	1.799	45112.	.053	76.60	80261.9	.002534
10	40.9	860.6	1.751	43155.	.058	72.71	80112.7	.002529
11	48.9	899.1	1.705	41502.	.061	70.30	80108.1	.002529
12	57.0	935.8	1.661	40009.	.065	68.12	79945.1	.002524
13	65.0	963.2	1.613	38674.	.069	67.21	79895.4	.002522
14	73.4	994.9	1.570	37386.	.073	66.24	79717.1	.002517
15	81.6	1019.8	1.527	36270.	.081	65.85	79238.7	.002503
16	90.4	1016.5	1.457	35182.	.126	67.60	76066.3	.002401
17	98.4	751.4	1.159	34529.	.522	131.51	51867.8	.001637

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	74.6	1.24	75.2	-.514E-02
2	90.4	63.3	1.46	553.9	.244E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
45515.	28654.	.00530

RUN 163H, DATE 04/08/76, GAS AIR , MOLECULAR WT. = 28.97
TIN = 76.8 F, TOUT = 345.4 F, MASS FLOW RATE = 11.8 LB/HR, I = 64.4 AMPS, E = 3.635 VOLTS
PR.IN = .719, GR/RESQ = .572E-03, MACH(2) = .110, MACH(16) = .145, T,SURR = 83.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	152.0	1.140	32842.	.201	194.33	21115.9	.001133
3	1.2	215.8	1.255	32706.	.252	99.01	19591.1	.001067
4	2.1	255.2	1.321	32594.	.104	90.78	23143.7	.001242
5	4.1	292.9	1.377	32326.	.063	79.01	24107.5	.001294
6	8.1	325.6	1.410	31818.	.050	70.96	24466.2	.001313
7	16.4	365.0	1.419	30830.	.049	64.45	24565.7	.001319
8	24.5	392.0	1.410	29959.	.050	61.30	24589.1	.001320
9	32.4	415.0	1.397	29141.	.051	59.22	24602.4	.001321
10	40.8	439.8	1.383	28349.	.056	57.27	24533.4	.001317
11	48.7	462.3	1.372	27650.	.058	55.52	24528.5	.001317
12	56.9	482.5	1.356	26998.	.062	54.46	24456.1	.001313
13	64.8	499.9	1.338	26389.	.063	54.08	24463.0	.001313
14	73.2	523.5	1.328	25783.	.071	52.19	24321.5	.001305
15	81.3	539.1	1.309	25247.	.079	52.21	24198.7	.001299
16	90.1	544.5	1.277	24714.	.143	52.17	22817.7	.001225
17	98.1	393.1	1.065	24334.	.385	181.09	18639.4	.001000

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	59.2	1.12	75.3	-.533E-02
2	90.1	57.1	1.28	325.5	.138E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
28736.	21742.	.00612

RUN 164H, DATE 04/08/76, GAS AIR , MOLECULAR WT. = 28.97
TIN = 77.2 F, TOUT = 473.1 F, MASS FLOW RATE = 11.9 LB/HR, I = 79.0 AMPS, E = 4.565 VOLTS
PR.IN = .719, GR/RESQ = .644E-03, MACH(2) = .117, MACH(16) = .159, T,SURR = 84.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	179.9	1.190	32977.	.176	219.43	32530.2	.001734
3	1.2	280.5	1.367	32771.	.291	102.21	29850.6	.001592
4	2.1	338.2	1.465	32602.	.106	93.49	34992.6	.001566
5	4.1	395.6	1.547	32203.	.069	80.22	36350.3	.001938
6	8.1	446.3	1.594	31475.	.057	70.66	36896.2	.001967
7	16.4	509.8	1.603	30079.	.057	62.60	37052.3	.001976
8	24.5	550.9	1.582	28842.	.059	58.65	37081.2	.001977
9	32.4	585.0	1.554	27779.	.062	56.22	37093.5	.001978
10	40.8	613.4	1.523	26772.	.068	54.03	36969.4	.001971
11	48.8	649.6	1.497	25886.	.070	52.17	36956.6	.001971
12	56.9	679.7	1.470	25083.	.077	50.65	36809.3	.001963
13	64.9	703.5	1.439	24345.	.079	50.46	36794.3	.001962
14	73.3	731.2	1.412	23654.	.087	49.51	36011.0	.001952
15	81.4	754.6	1.385	23024.	.096	49.05	36347.7	.001938
16	90.2	753.1	1.336	22410.	.168	49.35	34115.2	.001819
17	98.2	536.9	1.063	22026.	.564	196.02	25089.3	.001338

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	59.1	1.16	77.2	-.583E-02
2	90.3	56.6	1.33	451.9	.222E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
27706.	19706.	.00599

RUN 165H, DATE 04/08/76, GAS AIR , MOLECULAR WT. = 28.97
TIN = 77.7 F, TOUT = 623.1 F, MASS FLOW RATE = 11.8 LB/HR, I = 93.0 AMPS, E = 5.535 VOLTS
PR.IN = .719, GR/RES2 = .116E-02, MACH(2) = .117, MACH(16) = .172, T,SURR = 85.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	220.1	1.262	32826.	.174	220.63	45309.1	.002420
3	1.2	361.7	1.510	32541.	.300	100.67	41322.3	.002267
4	2.1	443.9	1.647	32307.	.110	92.11	46679.7	.002500
5	4.1	530.8	1.768	31754.	.080	77.17	50346.0	.002669
6	8.1	612.7	1.838	30792.	.070	60.52	51122.5	.002731
7	16.4	704.5	1.841	29953.	.072	57.21	51352.9	.002743
8	24.6	763.0	1.798	27443.	.077	52.68	51316.7	.002741
9	32.5	809.5	1.746	26163.	.081	50.01	51273.8	.002739
10	40.9	851.3	1.691	24977.	.089	47.72	51064.9	.002728
11	48.9	889.7	1.642	23975.	.093	46.33	50952.7	.002723
12	57.0	925.6	1.595	23077.	.101	45.01	50765.7	.002712
13	65.0	954.2	1.546	22264.	.105	44.63	50651.5	.002706
14	73.4	989.3	1.506	21515.	.114	43.74	50361.8	.002691
15	81.6	1015.9	1.464	20641.	.126	43.62	49917.9	.002666
16	90.4	1019.0	1.402	20216.	.204	43.56	46660.7	.002493
17	98.4	707.4	1.073	19871.	.967	144.55	27984.5	.001495

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	59.1	1.22	78.2	-.583E-02
2	90.4	56.0	1.40	595.5	.268E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
26540.	17482.	.00613

RUN 167H, DATE 04/08/76, GAS AIR , MOLECULAR WT. = 28.97
TIN = 75.4 F, TOUT = 177.1 F, MASS FLOW RATE = 11.8 LB/HR, I = 39.8 AMPS, E = 2.310 VOLTS
PR.IN = .720, GR/RES2 = .216E-03, MACH(2) = .117, MACH(16) = .127, T,SURR = 80.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	99.9	1.047	33124.	.109	247.26	8711.1	.000469
3	1.2	126.0	1.094	33070.	.273	105.44	7597.3	.000407
4	2.1	140.6	1.120	33025.	.091	96.19	8873.1	.000475
5	4.1	154.6	1.141	32922.	.051	83.70	9216.3	.000493
6	8.1	166.5	1.154	32722.	.037	75.53	9353.6	.000501
7	16.4	180.1	1.161	32313.	.035	71.49	9375.0	.000502
8	24.5	190.1	1.161	31927.	.036	69.46	9376.9	.000502
9	32.3	198.8	1.159	31572.	.037	68.30	9371.3	.000502
10	40.7	207.5	1.156	31204.	.039	67.46	9357.1	.000501
11	48.7	216.4	1.154	30862.	.041	66.33	9353.4	.000501
12	56.8	225.8	1.154	30522.	.044	64.72	9329.8	.000499
13	64.7	233.0	1.149	30197.	.045	64.81	9325.9	.000499
14	73.0	242.5	1.148	29863.	.049	63.35	9295.5	.000498
15	81.2	250.1	1.145	29545.	.056	62.39	9239.8	.000495
16	89.9	252.9	1.133	29221.	.103	64.07	8850.4	.000474
17	97.9	194.3	1.027	28972.	.174	317.76	8274.1	.000443

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-.5	59.0	1.04	74.4	-.532E-02
2	90.0	57.5	1.13	169.4	.136E+01

AVERAGE PARAMETERS BETWEEN PRESSURE TAPS

AVERAGE BULK REYNOLDS	AVERAGE WALL REYNOLDS	AVERAGE FRICTION FACTOR
31175.	27258.	.00581

APPENDIX E.
Thermocouple Conduction Error

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A thermocouple attached to the outside surface of a heated tube acts as a fin or extended surface which lowers the temperature at the point of attachment. Since this point also serves as the thermocouple junction, it measures a wall temperature lower than the value which would occur without its presence. The difference is known as "thermocouple conduction error." Consequently, in an experiment such as the present study, the deduced Nusselt number is systematically increased unless corrected for this effect.

Analyses

Based on extended surface analyses, the normalized thermocouple conduction error θ has been shown by Schneider [48] to be approximately

$$\theta = \frac{t_w - t_{TC}}{t_w - t_\infty} = \left[1 + \frac{2\pi k_{tube}\delta_{tube}}{h_{TC}A_s} \lambda r_o \frac{K_1(\lambda r_o)}{K_o(\lambda r_o)}\right]^{-1} \qquad \text{(E1)}$$

where t_w is the temperature of the undisturbed tube, $h_{TC}A_s$ is the thermocouple conductance and r_o is the effective radius of the thermocouple attachment. K_o and K_1 are modified Bessel functions of the second kind of order zero and one, respectively [49,50]. The quantity λ is defined as

$$\lambda = \frac{h_o + h_i}{k_{tube}\,\delta_{tube}}$$

and the thermocouple conductance is defined by the equation

$q_{TC} = h_{TC}A_s(t_{TC}-t_\infty)$. Thus, in this approximation θ is a function of the non-dimensional parameters λr_o and $M = k_{tube}\delta_{tube}/(h_{TC}A_s)$.

Using approximations to the Bessel functions, valid at small values of the argument, one may reduce equation (E1) further so that it takes the form

$$\theta \approx -\ln(\lambda r_o)/2\pi M \qquad \text{(E2)}$$

when $2\pi M >> 1$. This form is useful for estimates of the maginitude of θ when desiring to determine whether it is significant in a given case. It is presented as Figure E1.

In calibration for thermocouple conduction error data are normally obtained without flow so a probe can be used to measure the tube wall temperature in the vicinity of the thermocouple. In this case, $h_i = 0$. Examining Figure E1, one can see that the effect of flow (i.e., non zero value of h_i) is to increase λr_o and reduce θ for the same thermocouple attachment and environment.

Hess [29] extended and improved Schneider's analysis for application to electrically heated tubes with internal flow such as the present experiment. His representation takes the form

$$\theta = \frac{(1-h_o/h_{TC})}{\dfrac{h_i + h_o}{h_{TC}} + \dfrac{2k_w\delta}{h_{TC}r_o^2}\,\dfrac{\lambda r_o K_1(\lambda r_o)}{K_o(\lambda r_o)}} \qquad \text{(E3)}$$

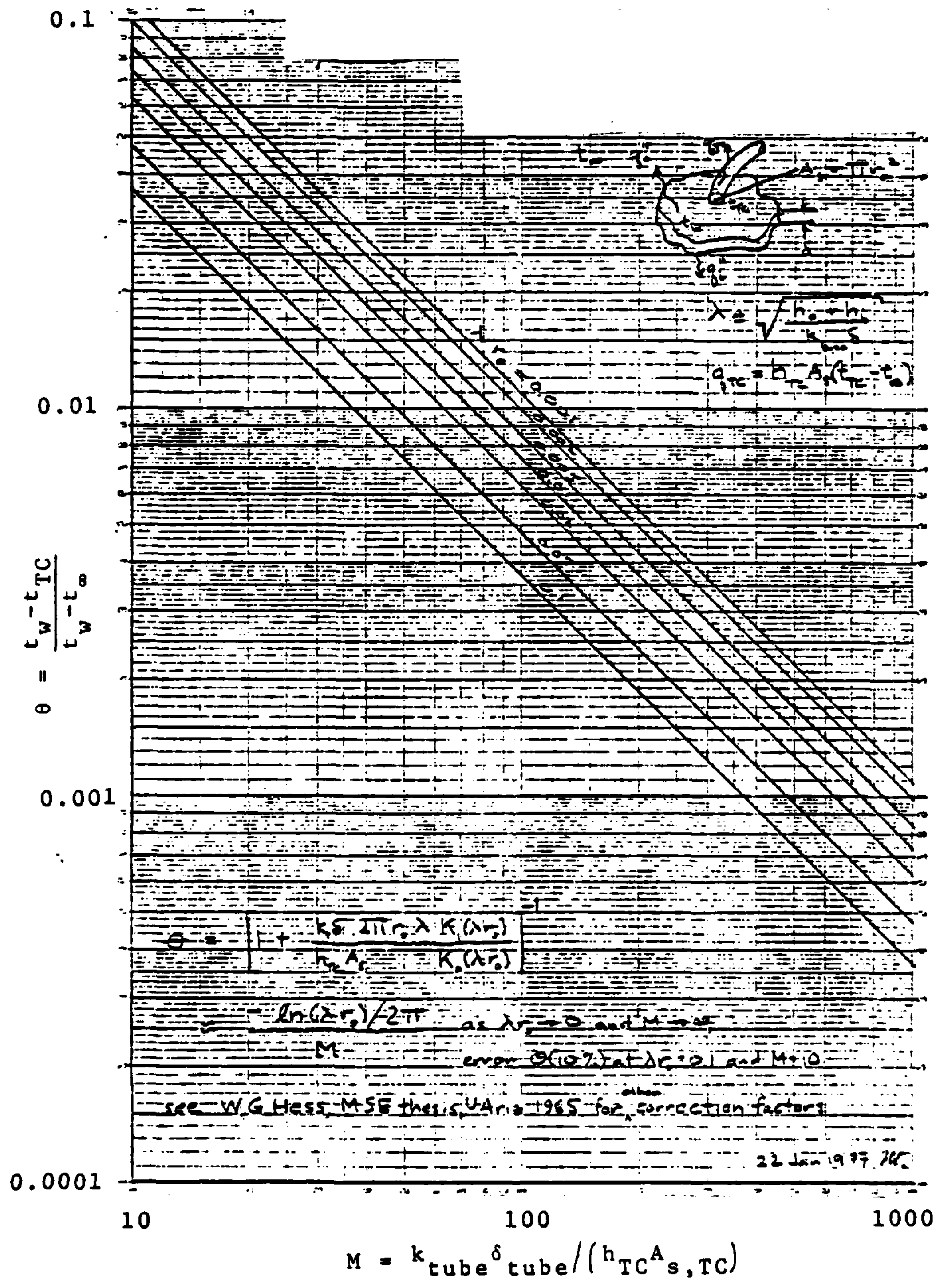

Fig. E1. Approximation to thermocouple conduction error for large values of parameter $M = k_{tube}\delta_{tube}/(h_{TC}A_{s,TC})$.

Evaluation of thermocouple conductance, $h_{TC}A_s$

For fine wire thermocouples in an environment at atmospheric pressure, free convection dominates as the mechanism for heat loss from the thermocouple compared to radiation. As an approximation, one may consider the total heat transfer coefficient and properties to be constant for the thermocouple wire and derive

$$q_{TC} = \sqrt{(h_r + h_{NC})Pk_{TC}A_{CS}}\,(t_{TC}-t_\infty)\tanh m\ell \qquad \text{(E4)}$$

as by Schneider [48]. For long wires, i.e., $m\ell = \sqrt{\ell\, hP/kA} > 5$, $\tanh m\ell$ approaches unity; then $h_{TC}A_S$ becomes $\sqrt{(h_r + h_{NC})Pk_{TC}A_{CS}}$.

The wire can be considered a small body in large surroundings so

$$h_r \approx \varepsilon\sigma\,[T_{TC}^4 - T_\infty^4]/(T_{TC}-T_\infty) \qquad \text{(E5)}$$

The heat transfer coefficient for natural convection can be determined from a correlation of the form $Nu_f = fn(Gr_f Pr)$. The Grashof number is typically small for wires of the size of our thermocouples. For the range $10^{-3} < GrPr < 10^{-1}$ the curve recommended by Kreith [51, Fig.7-3] can be represented as

$$Nu_f = \frac{h_{NC}d}{K_f} = 0.315 + 0.8\,[Gr_f Pr_f]^{0.18} \qquad \text{(E6)}$$

In an unpublished note, Hess, Deardorff and McEligot [52, included herein as Appendix F] examined available calibration data for radiating thermocouples attached in the parallel junction form of Moen [28]. From comparisons be-

tween predictions and measurements, they concluded that the effective radius of the thermocouple attachment, r_o, was approximately equal to the actual radius of the thermocouple wire. Consequently, $A_s = \pi r_o^2 \approx A_{CS} = \pi d^2/4$. The calibration data of Campbell [53] for an atmospheric environment are also in approximate agreement with the choice of d/2 as r_o.

Application to present experiment

The heat transfer coefficient from the outside of the tube, h_o, may be deduced from the heat loss calibration equation (B5), to be

$$h_o = [C_1 + C_2(t_w - t_\infty) + C_3(t_w - t_\infty)^2]/\pi D \qquad (E7)$$

For h_i either a correlation such as equation (19) or tabular data from the initial data reduction can be employed. In this experiment h_i is typically of the order of 200 Btu/hrft^2°F or more.

As an example of the magnitude of thermocouple conduction error to be expected, Figure E2 has been plotted for thermocouple 10. The value of h_i was taken as 200 Btu/hrft^2°F and the environmental temperature was assumed to be about 70°F for this presentation. The reduction in θ with flow is clear and it is also seen that in the heat loss runs (no flow) θ decreases slightly as the wall temperature increases.

For the tabular results of Appendix D the thermocouple conduction error was calculated from equations (E3) through (E7) and correlations (19) and (B5). Material and fluid

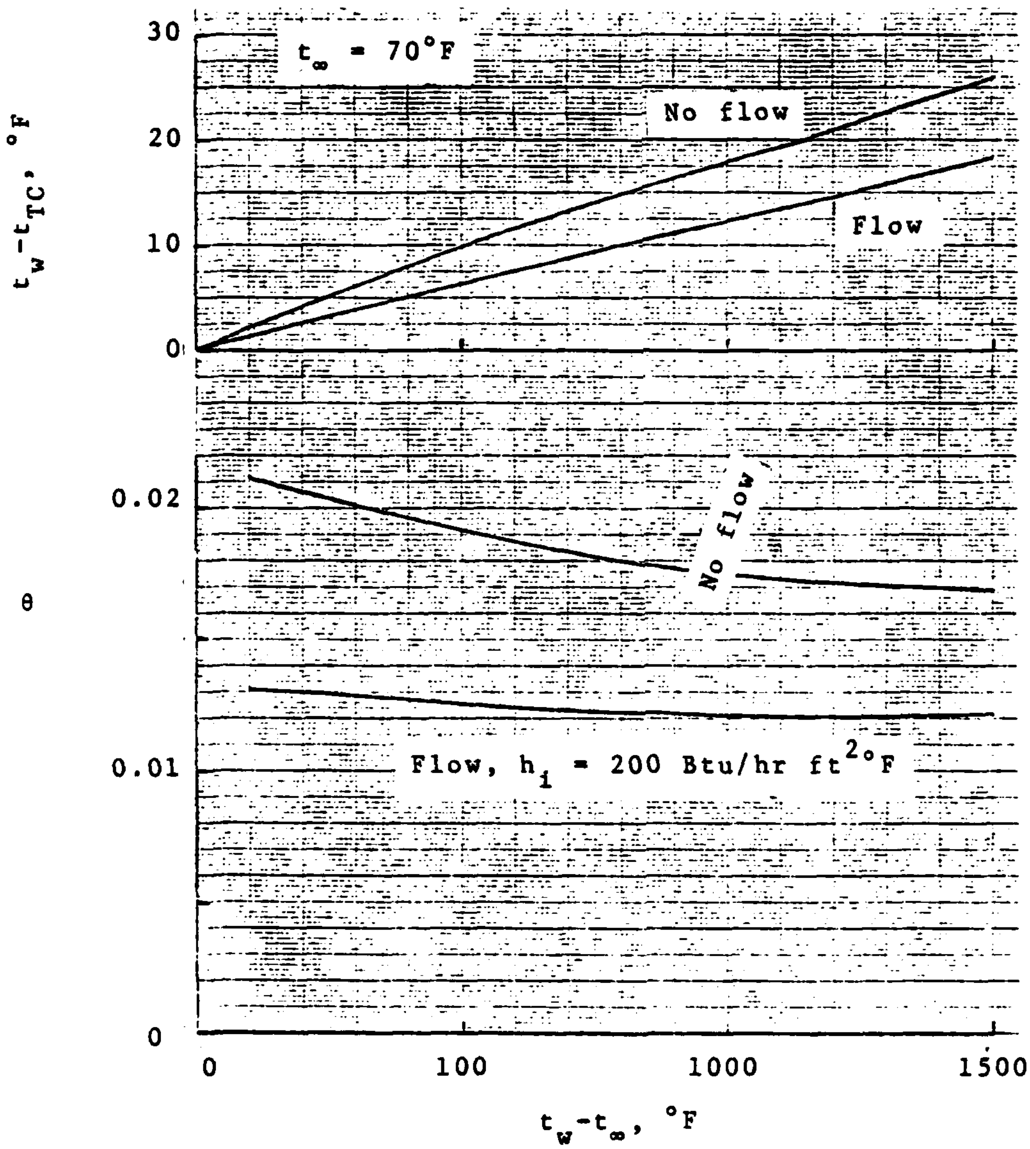

Fig. E2. Predicted thermocouple conduction error for thermocouple 10.

properties used in evaluating the thermocouple conductance were based on the temperature at the junction and its resulting film temperature, $t_f = (t_{TC} + t_\infty)/2$, as appropriate. While a numerical solution could be applied to improve the analysis predicting the thermocouple conductance, such sophistication does not appear warranted due to the uncertain knowledge of several quantities and the small magnitude of θ.

APPENDIX F.
Radiating Thermocouple Conduction Error

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In space environments and space simulation chambers, temperatures are often measured with thermocouples attached to exposed surfaces. The primary means of energy exchange then are conduction through the solid material and thermal radiation. In our Laboratory, we . 'so often use a vacuum environment to minimize and/or localize the heat loss from thin-walled tubes in which we perform internal convective heat transfer measurements [38]. In these situations the thermocouple attachment usually acts as a radiating fin which reduces the local surface temperature near the point of measurement. This systematic effect may be called the radiating thermocouple conduction error.

Schneider [48] presents an analysis to predict the thermocouple conduction error in a convective environment by idealizing the thermocouple as a cylinder mounted perpendicular to the surface at a single point.

1. Now with Pratt and Whitney Aircraft Company, West Palm Beach, Florida.
2. Now with Gulf General Atomics, La Jolla, California.

Including energy generation in the wall by electrical resistive heating and energy transfer from the surface opposite the idealized thermocouple, one may extend Schneider's result to

$$\frac{T_{TC} - T_{w,u}}{T_{w,u} - T_\infty} = \frac{(h_o - h_{TC}) r\, K_o(\lambda r)}{(h_i + h_{TC}) r\, K_o(\lambda r) + 2\lambda k_w \delta K_1(\lambda r)} \quad \text{(F1)}$$

where the heat transfer coefficients may represent convective or radiative processes as appropriate. In the case of infinite radiating thermocouple leads, the effective heat transfer coefficient over the contact area of the thermocouple may be shown to be

$$h_{TC} = \frac{k_{TC}\left[\frac{2\beta}{5}\left(T_{TC}^5 - 5T_{TC}T_\infty^4 + 4T_\infty^5\right)\right]^{\frac{1}{2}}}{T_{TC} - T_\infty} \quad \text{(f2)}$$

if its emissivity and thermal conductivity are constant. Thus, provided that the material properties are known, prediction of the radiating thermocouple conduction error reduces to the problem of determining the effective thermocouple radius, r.

For many applications the parallel type thermocouple junction, shown in the insert of Figure F1, is more accurate than the more common cross type junction because the location of the measuring plane is effectively on the tube surface rather than being spread perpendicular to it [28].

Rather than satisfying the idealization of a single cylindrical interface between the thermocouple and the surface, the attachment region for the parallel junction consists of two roughly elliptical areas slightly separated from each other. Accordingly, the objectives of the present work were taken to be (1) to determine r for a parallel junction configuration and (2) to investigate the reproducibility of the conduction error when such thermocouples are produced by using normal laboratory standards for equipment construction.

Measurements were conducted on three circular test sections of 0.010 inch thick Inconel 600, two feet long. Premium grade bare Chromel and Alumel thermocouple wires of 0.005 inch diameter were spot welded to the test section by the electrical discharge technique. Circumferential distance between the two wires was approximately 1/8 inch and the attached area of each covered approximately one to two wire diameters. Tests included about fourteen such thermocouples with all wires taken from the same spools.

These resistively heated test sections were mounted in glass vacuum chambers. With no intermal flow, h_i equals zero and h_o can be determined from the tube emissivity which one also deduces from the tests. "Undisturbed"

tube wall temperatures, $T_{w,u}$, were determined with a traveling internal thermocouple probe, also of premium grade Chromel-Alumel, which measured the wall temperature profile axially betwenn the thermocouples. Calculations show the maximum temperature drop through the wall to be less than 0.01°F so the thin wall idealization is valid. Readings were accepted without correction for deviation from standard N.B.S. emf tables since Hoskins Manufacturing Company certified the deviation as less than 1°F.

Results are demonstrated on Figure F1. The dashed curves are predictions based on equations (F1) and (F2) in conjunction with manufacturers' information for emissivities and thermal conductivities of the thermocouple wires and the tube. The solid curve represents predictions based on the measured emissibity of the Inconel tube used by Hess and on an effective thermoucouple radius equal to the actual wire diameter; otherwise the bases are the same.

Hess' data points are averages of the thermocouple readings for the central protion of the tube and they show the effective radius to be approximately equal to the wire diameter or slightly less. The measurements of Swearingen and of Reynolds and Deardorff are from test sections with different thermal histories, hence

emissivities, but of the same materials and dimensions. Their calibrations suggest that r is about one-half the wire diameter. Different welding jigs were used for each and, consequently, the region of attachment varied from test section to test section but would be approximately uniform for different thermocouples on the same test section. Accordingly, one would expect the level of the thermocouple conduction error to vary from test section to test section as it does in Figure F1.

We conclude that the effective radius of the thermocouple attachment is approximately one-half to one wire diameter when constructed in the manner described. One may use this observation with manufacturers' information and equations (F1) and (F2) to determine whether the systematic error will be significant in his specific application. (For the results shown, in an internal convective heating experiment with $T_w \simeq 1000°F$ and $T_b \simeq 900°F$, the resulting error in Nusselt number would be 5 to 10 per cent.) If such predictions indicate that the errors would be important, we recommend individual calibration since the values of a number of the pertinent input variables are not readily available.

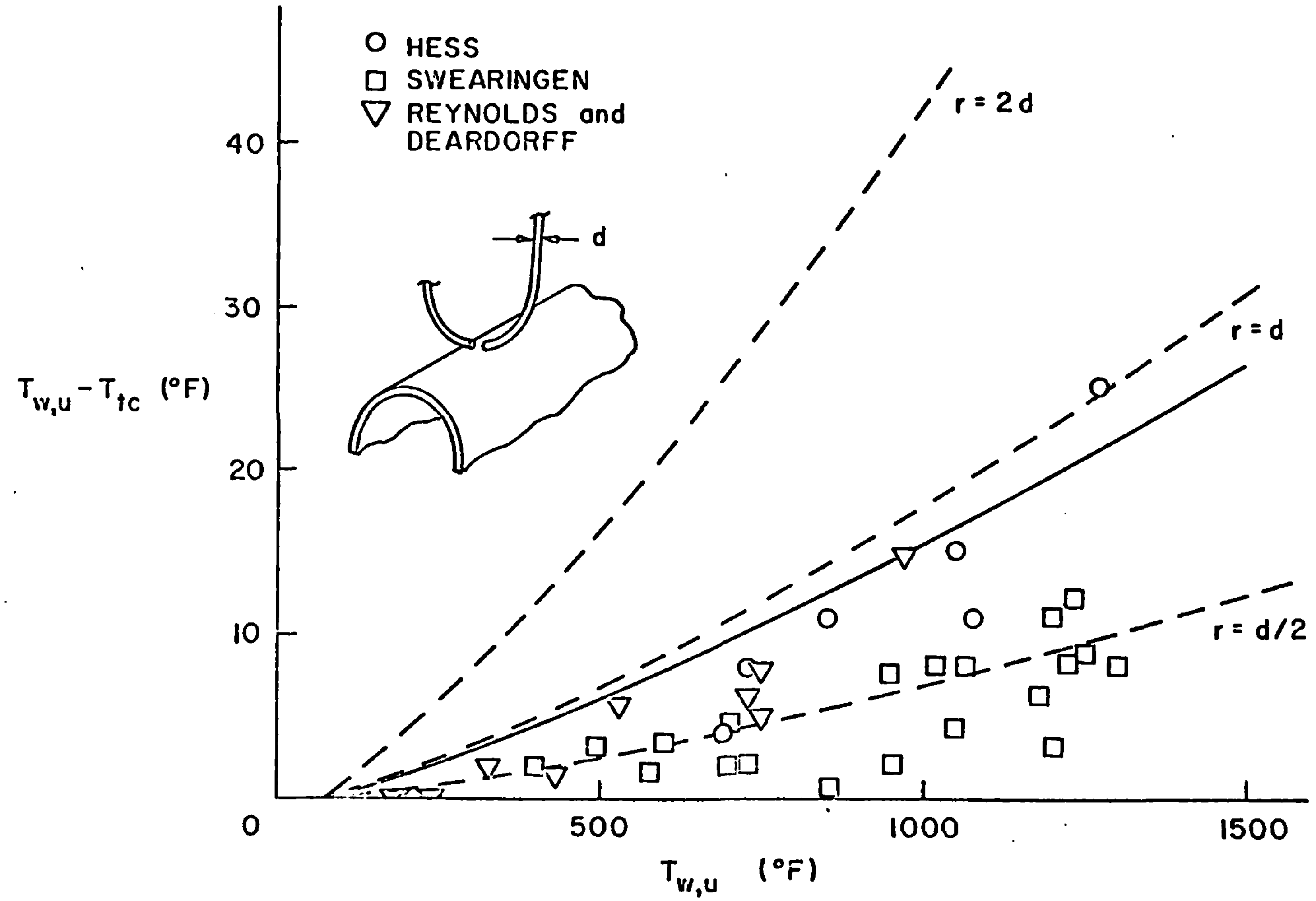

Figure F1. RADIATING THERMOCOUPLE CONDUCTION ERROR FOR PARALLEL TYPE JUNCTION

NOMENCALTURE

h	Heat transfer coefficient; h_i, inner surface: (thermocouple) surface.
k	thermal conductivity
K_o, K_1	Bessel functions
r	effective thermocouple attachment radius
T_{TC}	temperature measured by thermocouple
$T_{w,u}$	"undisturbed" wall temperature
β	thermocouple heat transfer constant, $2\sigma\varepsilon/(k_{TC}r)$
δ	wall thickness
ε	emissivity
λ	wall heat transfer constant, $[h_o + h_i)/(k_w r)]^{\frac{1}{2}}$
σ	Stefan-Boltzman constant

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